University of Alberta

Geological and geochemical links between Quesnel "terrane" strata and ancestral North America, southern Canadian Cordillera

by

Jennifer Lee Esther Unterschutz ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

Department of Earth and Atmospheric Sciences

Edmonton, Alberta

Fall 2002

National Library of Canada
Acquisitions and Bibliographic Services
395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale du Canada
Acquisitions et services bibliographiques
395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-81490-4

Canada

Univeristy of Alberta

Library Release Form

Name of Author: Jennifer Lee Esther Unterschutz

Title of Thesis: Geological and geochemical links between Quesnel "terrane" strata and ancestral North America, southern Canadian Cordillera

Degree: Master of Science

Year this Degree Granted: 2002

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as herein before provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

#50, 843 Youville Drive West
Edmonton, Alberta, Canada
T6L 6X8

Submitted May 13, 2002

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Geological and geochemical links between Quesnel "terrane" strata and ancestral North America, southern Canadian Cordillera** by Jennifer Unterschutz, in partial fulfillment of the requirements for the degree of Master of Science.

Dr. Philippe Erdmer
(Supervisor)

Dr. Thomas Chacko

Dr. Dwayne Tannant

16th May 2002.

Abstract

The contact between North American strata and the Quesnel "terrane" in southeastern B.C. has been interpreted as a fault, yet mapped as an unconformity. This study shows that the contact is unexposed in the Silver Star area (near Vernon, B.C.). New geochemical and Nd isotopic provenance studies of Triassic clastic metasedimentary rocks assigned to the Quesnel "terrane" in southeastern B.C. show that detritus was derived from both primitive and evolved sources, which were proximal and are geochemically indistinguishable from the Quesnel volcanic arc and Canadian miogeocline, respectively. Twenty-four samples yield εNd_{220} values between –9.1 and +5.6, Eu anomalies between 0.6 and 1.0, and La_N/Yb_N ratios between 3.8 and 11.4. Detrital zircons (~192 Ma) from the Quesnel "terrane" show evidence of Proterozoic inheritance. This inferred Triassic to early Jurassic depositional link between North America and the Quesnel "terrane" suggests a pericratonic, non-exotic, origin for the Quesnel terrane in southeastern B.C.

To my parents:
Collin and Doreen

Opportunity is nothing
without belief in oneself.

You gave me that.

Acknowledgements!

Thank you. These are words I wish to express to a number of individuals who have, throughout the last four years, made this mammoth undertaking possible. It is difficult to know where to begin, as completion of a graduate program is so much more than an education in writing a thesis and conducting research. We are inducted into the world of academia, for better or worse, and often are given views into human nature that are as enlightening and exciting as they can be disappointing. Not to mention what you learn about yourself! As the course of these past four years has brought many people into my life, I will start at the beginning, and hope that I don't miss anyone. If I do, forgive me.

This project would not have been possible without Bob Thompson at the Geological Survey of Canada, who co-ordinated it and financially supported a large portion of the mapping, not to mention a hungry grad student for the summer. I thank Bob for this opportunity, for his time, thoughts, geological discussion, and timely advice, and also for opening his home and family to my presence in Sidney while completing the map. I am also grateful for financial support for this project and myself from Philippe Erdmer, through NSERC grants. I thank Robert Creaser for listening to my ideas on sediment geochemistry and supporting them both scientifically and financially, and for helping me to understand the world of Nd isotope geochemistry. Tom Chacko I thank for all his time and patience, and his ability to make the world of metamorphic petrology understandable. Ken Daughtry, I thank for his endless patience and his generosity with time and resources, his kindness and friendship, and his knowledge of, and passion for, southeast B.C. geology that is second to none, and which always comes to surface during field trips that he is happy to lead 2 to 20 people on at the drop of a hat. And finally, I thank Larry Heaman for his time and introduction into the world of U-Pb isotope geochronology, and for support and encouragement at the time when I needed it most. For financially supporting my health and well-being, I thank the University of Alberta, Province of Alberta, and Department of Earth and Atmospheric Sciences. This support assured that the ascent to grad school really was a step up in the world from undergrad, and that there would be no more ichiban for me, unless I chose to eat it, of course!

There were many in the NATMAP and structural community at large who are too numerous to mention, but I would like to thank all of those whom

I either learned directly or indirectly from, and especially those of you who set foot in the Vernon area and gave freely your insights and ideas on outcrops within my field area, both in daylight and illuminated by headlight.

The University of Alberta has an extremely large geoscience grad student population, and some of my best memories come from experiences with my fellow students, geological and non-geological alike. They are certainly what has been the most difficult for me to leave behind. To you all - a huge thank you. You rock! Foremost, I thank Paul Glombick, fellow Erdmite and Vernon mapper, his friendship and geological discussions I valued throughout my time at the U of A. Karen "Fallaciraptor" Fallas, head Erdmite, I thank for leading the way and her endless patience with all my silly questions, and for her friendship. I thank the friendly neighborhood post-docs George Morris and Chris Böhm for their assistance in the world of geochemistry and isotope geology. I benefited from friendship and discussion with many of my fellow students, and I thank all of them, especially those of you on the intramural teams that I found so central to my sanity - Go Bedrockers Go! There are, however, a few friends who I'd like to thank specifically, for their much needed friendship, support, and appetite (apatite?) for fun, and they include Russell "the muscle" Hartlaub, Rajeev Nair, Poulomi Sannigrahi, Nadya Slemko, Mark Smith, and Alex MacNeil.

David "Wavey" Selby - this paper isn't big enough to list all the things I have to thank him for, but, putting his amazing friendship and bottomless support aside, it's probably best summed up by the fact that he's the only person to have read my thesis outside of my thesis committee! His support was invaluable, and I was indeed lucky to have it.

In and out of the geology world, both in roles as field assistant and friend, Elizabeth L'Heureux deserves grand kudos. And not just because she's one of my best friends and favourite people in the world, but for never complaining and for her ability to make even the most miserable field days fun. Or maybe funny is more accurate. And along with Liz, I have a huge thanks to offer to the L'Heureux Family: Art, Catherine, Matt, Andy, Theresa and Steve. The L'Heureux's not only opened up their home in Vernon as a logistical base for us, but they were always willing to lend a hand when things got messy, stuck, or down right ugly. If you're visiting the Vernon area, there's no better place to go. I thank them for their patience, their kindness, their friendship, and never ending humor. Matt in particular I thank for a season of beach volleyball, which gave me an excuse to come

into town once a week and was a great outlet for frustration (not that grad students have any of that!).

To my office mate Gabriel J. Wolken - thanks for finding my coloured conversations with my computer amusing, for joining me on afternoon trips to visit Timmy, and your friendship. And for the forwards of messages from my plants while I was away.

Outside of the University there are several people who helped keep me sane. Carla Zittlau, my sister, I thank you for your voice of reason and open ear, and your friendship, which I treasure. Jacey Payne, I thank you for your sympathetic ear, and for all the dancing therapy sessions! They were invaluable.

I am lucky to have the incredible support network of most of my relatives in the greater Edmonton area. I thank them for never failing to rally every four or eight months to move me, yet again. That is invaluable! But I also thank them for their undying support through the ups and downs, and for caring. It's surprising what a difference that can make. My brother deserves special mention for the multiple times he helped me haul about buckets of rocks, and rocks themselves. Thank goodness for relatives!

And finally my folks. Not only did they give birth to me, but they insisted that I go out into the world with a belief in myself that was certainly put to the test in the last four years, but that came out unfalteringly. Nice work. I don't think I can ever thank them enough. I only hope that they realize that a large part of my success at this is due to them, their support, and love. This I cherish.

There were several points during my program at which I wondered why the heck I decided to do this. But as I look back at what I've written here, it becomes clear. Not only were the rocks cool, but the experience and people along the way were cooler.

Table of Contents

Chapter — Page

1. Introduction....1
   - References....7

2. Geology of the Silver Star area, southeastern British Columbia: Implications for an early Jurassic link between the Quesnel terrane and ancestral North America
   - Introduction....9
   - Geologic Setting
     - Regional Framework....10
     - Previous Mapping....13
   - Geology
     - Layered Units....13
     - Igneous Units....25
     - Structural Geology....28
       - Folding....28
       - Faulting....30
       - Discussion of Cross-Sections....32
     - Metamorphism....32
   - Geochronology
     - Methodology and Analytical Technique....33
     - Sample Descriptions....34
     - Zircon Descriptions and Results....35
     - Interpretations and Implications....36
   - Isotope Geochemistry
     - Sampling Methodology....39
     - Analytical Technique....39
     - Results and Interpretations....40

Discussion

Geologic History.....41

North American Ties.....44

Appendix 2-1.....69

Appendix 2-2.....83

References.....96

3. North American margin origin of Quesnel terrane strata in the southern Canadian Cordillera: Inferences from geochemical and Nd isotopic characteristics of Triassic metasedimentary rocks

Introduction.....102

Geologic Framework.....105

Previous Nd Isotope and Geochemical Studies.....106

Sampling Method and Analytical Technique.....107

Results

Petrography.....108

Major Element Chemistry.....109

Trace Element Chemistry.....109

Nd Isotopic Data.....110

Discussion and Implications

Sediment Source.....111

A North American Source?.....112

Other Possibilities.....113

Implications

Quesnel Terrane.....113

Tectonic Setting.....114

Conclusions.....116

References.....131

4. Concluding Remarks.....136

References.....138

List of Tables

Table Page

Chapter 2

2-1 Outcrop locations and descriptions of conglomerate units possibly correlating with Mcgl..... 47

2-2 U-Pb zircon results for samples from Silver Star area, southeastern British Columbia..... 48

2-3 Sm-Nd results for samples from the Silver Star area, British Columbia..... 49

Chapter 3

3-1 Major and trace element concentrations and calculated ratios..... 117

3-2 Rock type, Sm and Nd concentrations, and isotopic data..... 119

3-3 Sample locations..... 120

List of Figures

Figure		Page
Chapter 1		
1-1	Simplified tectonic assemblage maps showing study areas	6
Chapter 2		
2-1	Geological map of the Silver Star area	in pocket
2-2	Regional geology of southeastern British Columbia	50
2-3	U-Pb concordia plot of zircons from 00 JU 01 (Jgtd)	52
2-4	U-Pb concordia plots of zircons from JU SS CGL (Mcgl)	53
2-5	Equal area plots of poles to S_2 surfaces	55
2-6	Equal area plots of poles to bedding/compositional layering (S_0) surfaces	56
2-7	Equal area plots of poles to S_1 surfaces	57
2-8	Equal area plots of lineations	58
2-9	U-Pb Concordia plot of zircons from 00 JU 02	59
Chapter 3		
3-1	Maps showing regional geology and location of samples with εNd data	121
3-2	Stratigraphic correlation chart of Triassic metasedimentary rocks, southeastern B.C.	122
3-3	$Log(Na_2O/K_2O)$ vs. $Log(SiO_2/Al_2O_3)$ chemical classification	123
3-4	Chondrite normalized rare earth element plot	124
3-5	Trace element variation diagrams	125
3-6	La-Th-Sc and Th-Sc-Zr/10 ternary diagrams	126
3-7	Sm-Nd isotopic system: εNd_{220} vs. $^{147}Sm/^{144}Nd$	127
3-8	εNd_{220} range vs. grain size	128
3-9	εNd_{220} vs. latitude and longitude	129
3-10	εNd_T vs. latitude and longitude for late Triassic through Tertiary igneous rocks, southeast B.C. (from Ghosh, 1995)	130

List of Plates

Plate		Page
Chapter 2		
2-1	Units Pgn, Dcq, Pcs, Pscgl, and Pccs	60
2-2	Units Pscmb, Maug, Ms, Esbr, and Esp	61
2-3	Mcgl and possible correlative units to Mcgl	62
2-4	Structure: folding and faulting	63
2-5	Asymmetric shear sense indicators	64
2-6	Metamorphic minerals	65
2-7	Zircon fractions from 00 JU 01 (Jgtd)	66
2-8	Zircon fractions from 00 JU 02 (Silver Star Intrusions)	67
2-9	Detrital zircons from JU SS CGL (Mcgl)	68

Chapter 1

Introduction

The North American Cordillera is a mountain belt that runs along the entire western margin of North America. The Canadian component is over 2000 km in length and 750 km in width (Fig. 1-1). This mountain belt has been studied for over a century, but it was not until the paradigm of plate tectonics became accepted in the 1970's that a real understanding of the processes responsible for this mountain belt became known. Interactions between the Pacific, Juan de Fuca, Gorda, and Explorer plates, and the now extinct Kula and Farallon plates with the North American plate were responsible for orogenesis. The west coast of North America was a dominantly passive continental margin until the opening of the present day Atlantic ocean in the late Early Jurassic, which catalyzed its transition into a compressive orogen (Coney 1972; Bond and Komintz 1984; Engebretson et al. 1985; Thompson et al. 1987; Monger 1989, 1997; and references therein).

The North American Cordillera is characterized by a large variety of rock types that are often localized in occurrence, including abundant oceanic rocks, and rare blueschist rocks, in the middle of what is now a major land mass. Plate tectonics provides a means for transporting and accreting these different rock assemblages to the margin of North America. In the Klamath Mountains of California, Irwin (1972) recognized these discontinuous rock assemblages, and designated them "terranes". This provided for the first time a method of dividing and classifying these disparate rock assemblages. The value of this methodology for mapping in the Cordillera was quickly recognized, and the definition of a terrane evolved into a "fault bounded slice of crust that possesses an internally consistent geologic record, but one that is distinct with respect to those of neighboring terranes". When an uncertain relationship between many of these terranes and North America was recognized, the term "suspect terrane" was conceived (Coney 1980). Previous geologic mapping was then revisited, and "terrane" assemblages were defined throughout the North American Cordillera. Coney (1980) estimated that > 70% of the North American Cordillera is composed of rocks of a suspect nature.

Terrane classification was applied to all rocks outboard of the North American margin, often before an allochthonous, or fault-bounded, character was demonstrated (Fig. 1-1). In support of the terrane system of classification is abundant paleomagnetic data from plutons throughout the Cordillera. Paleomagnetic investigations in many of these terranes identified igneous rocks with very different paleo-poles, at the time of their crystallization, when compared to contemporaneous rocks along the North American margin. In many cases paleontological investigations have also been used to support a distant origin for many of these terranes. However, the great transport distances interpreted based on these paleontologic and paleomagnetic data are often not supported by geologic evidence, and many discrepancies remain today. Research presented in Chapter 2 on the Quesnel terrane outlines such an example.

Subsequent to their earlier designation, some "terranes" have come to be recognized as not befitting the definition of a terrane. In some cases, such as the Kootenay terrane, a depositional relationship with North American margin rocks has been demonstrated, and these rocks can no longer correctly be referred to as "suspect", nor as a "terrane" (Coulpron and Price 1995). The work presented in this thesis focuses on another such discrepancy, in southeastern British Columbia, on the relationship between the easternmost of these purported accreted elements, the Quesnel terrane, and rocks now demonstrated to be tied to, or derived from North America (Fig. 1-1). The Quesnel terrane is defined as an intra-oceanic arc that formed, in places, on top of crust of oceanic character (Monger 1977, 1985; Mortimer 1986, 1987; Gabrielse et al. 1991; Monger et al. 1982, 1991; Souther 1991; Dostal et al. 2001). Over 200 km of west-to-east overlap between the Quesnel terrane and North America is estimated (e.g., Ghosh 1995, and references therein), although this fault has never been documented in the field. Paleomagnetic and paleontologic evidence suggests that this terrane formed significantly to the south of its present location, and remained there until the Cretaceous. In contrast, unconformable relationships have been reported between rocks of this terrane, and rocks tied to, or derived from, North America (Jones 1959; Read and Okulitch 1977; Klepacki 1983; Klepacki and Wheeler 1985; Höy and Andrew 1991; Roback and Walker 1995; Thompson and Daughtry 1996, 1997, 1998).

This thesis focuses on the geologic relationship between the Quesnel "terrane" and ancestral North America in southeastern British Columbia, Canada. Research is presented in two-parts, in paper format. Chapters 2 and 3 are independently complete studies, related to one another by their similar focus.

Chapter 2 presents a geologic study of the Silver Star area, where rocks of the Quesnel terrane are in contact with rocks of the pericratonic Kootenay "terrane". Six months of field work were undertaken to investigate this contact and determine its nature, in addition to determining the geologic history of the area. An interpretation of this history is presented, and the outcome suggests that an unconformable contact is possible, but, because the contact is unexposed in the Silver Star area, this study was not conclusive. Augmenting the geologic study, U-Pb geochronology revealed Jura-Cretaceous plutonism in the area, and suggested an easterly provenance for sedimentary rocks of the Quesnel terrane, from volcanic rocks with inheritance from Proterozoic crust. Nd isotope studies revealed an *in-situ* origin for granites on Silver Star Mountain, contamination of Eocene mantle melts by continental crust, and a continental origin for Paleozoic sedimentary rocks in the study area.

Logistical support for work in Chapter 2 was provided by NSERC grants to P. Erdmer, the Ancient Pacific Margin NATMAP project of the Geological Survey of Canada through R.I. Thompson, and K.L. Daughtry, at that time with Discovery Consultants in Vernon, B.C. I conducted the field work, data analysis, and wrote this chapter, with the intention of submitting for publication to the *Canadian Journal of Earth Sciences*. Co-authors on this paper will include P. Erdmer, R.I. Thompson, K.L. Daughtry, L.M. Heaman, and R.A. Creaser. Editorial comments for this chapter were received from P. Erdmer. I prepared the original geological maps and cross-sections in AUTOCAD format, which were given to R. Macleod of the Geological Survey of Canada for geo-referencing and integration into the NATMAP database, and for final digital cartographic preparation of the map. I prepared samples for U-Pb geochronology and Nd isotope analysis, which were then chemically processed and analyzed in the laboratories of L.M. Heaman and R.A. Creaser, respectively, at the Radiogenic Isotope Facility at the University of Alberta.

Chapter 3 presents a provenance study of Upper Triassic metasedimentary rocks of the Quesnel terrane, using Nd isotopes and trace element geochemistry. This study developed in response to the inconclusive mapping in the Silver Star area, and was designed as a test of the hypothesis that the Quesnel terrane could have developed unconformably on top of North American rocks. The test involved searching for detrital input from North American sources in these now metamorphosed sedimentary rocks. It also sought to test the validity of the classification of all Upper Triassic metasedimentary assemblages of oceanic character into the Quesnel terrane, by sampling rocks throughout this terrane in southeastern British Columbia, and examining their compositions in relation to their geographic position. This study suggests that these rocks are correctly designated as part of the same Upper Triassic succession, and that they consistently show derivation from two proximal sources, one with the primitive character of volcanic facies in the Quesnel terrane to the west, the other with a signature identical to more inboard deposits of the Cordilleran miogeocline to the east. This information, when combined with existing geologic data, strongly supports a pericratonic interpretation for the Quesnel strata, and suggests its status as being "suspect" or a "terrane" is incorrect.

The research presented in Chapter 3 was funded by NSERC grants to P. Erdmer and R.A. Creaser, and the Ancient Pacific Margin NATMAP project through R.I. Thompson at the Geological Survey of Canada. K.L. Daughtry contributed to scientific discussion. I completed the data analysis, and wrote this chapter. A version of this chapter has been accepted for publication in the Geological Society of America *Bulletin*, April 2002 issue, with co-authors R.A. Creaser, P. Erdmer, R.I. Thompson and K.L. Daughtry. Editorial comments were received from all co-authors, in addition to reviewers through the Geological Society of America *Bulletin*, including P.J. Patchett, L. Farmer, and an anonymous reviewer. Samples were crushed at the University of Alberta, three of which I completed myself, with the remaining prepared under the direction of R.A. Creaser. Samples were chemically processed and analyzed for Sm and Nd isotopic compositions in the lab of R.A. Creaser at the Radiogenic Isotope Facility at the University of Alberta. Major and trace element composition measurements were completed at Washington State University.

In conclusion, this study confirms what geologic mapping has been suggesting since the mid-1980's, that the "terrane" designation for Quesnel strata is inappropriate. This may be viewed by some as a simple problem of semantics, solved by redefinition of the term "terrane", or Quesnel itself, but it makes the point that certain assumptions made in regards to the origin of these disparate rock assemblages need revisiting, and that perhaps these rocks should be considered "innocent" of an allochthonous designation until proven "guilty".

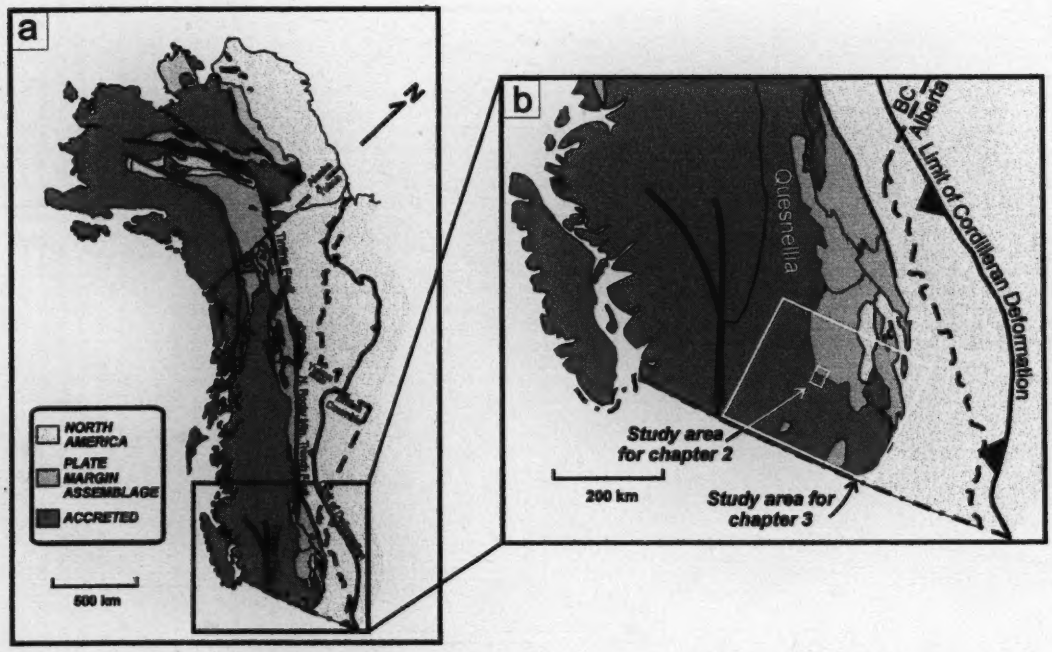


Figure 1-1. Simplified tectonic assemblage maps differentiating rocks interpreted to be of North American, plate margin assemblage, and accreted origin, showing (a) Canadian and Alaskan Cordillera, and (b) southeastern British Columbia. Figure (b) denotes the boundary of the Quesnel terrane and the study areas for chapters 2 and 3. The eastern extent of this mountain belt is indicated by solid lines marking the limit of deformation (modified from Wheeler and McFeeley 1991).

References

Bond, G.C., and Kominz, M.A. 1984. Construction of tectonic subsidence curves for the early Paleozoic miogeocline, southern Canadian Rocky Mountains: Implications for subsidence mechanisms, age of breakup, and crustal thinning. Geological Society of America Bulletin, **95:**155-173.

Coney, P.J. 1972. Cordilleran tectonics and North American plate motions. American Journal of Science. **272:**462-465.

Coney, P.J., Jones, D.L., and Monger, J.W.H. 1980. Cordilleran suspect terranes. Nature, **288:**329-333.

Coulpron, M. and Price, R.A. 1995. Tectonic significance of the Kootenay terrane, southeastern Canadian Cordillera: An alternative model. Geology. **23**(1):25-28.

Dostal, J., Church, B.N., Höy, T., 2001. Geological and geochemical evidence for variable magmatism and tectonics in the southern Canadian Cordillera: Paleozoic to Jurassic suites, Greenwood, southern British Columbia. Canadian Journal of Earth Sciences, **38**:75 - 90.

Engebretson, D.C., Cox, A., and Gordon, R.G. 1985. Relative motions between oceanic and continental plates in the Pacific basin. Geological Society of Special Paper 206. 59p.

Gabrielse, H., Monger, J.W.H., Wheeler, J.O. and Yorath, C.J. 1991. Part A: Morphogeological belts, tectonic assemblages, and terranes, *in* Gabrielse H. and Yorath, C.J., eds., Geology of the Cordilleran Orogen in Canada. Ottawa, Geological Survey of Canada, no.4, pp. 15-28. (also Geological Society of America, The Geology of North America, **G-2)**

Höy, T., and Andrew, K. 1991. Geology of the Rossland area, southeastern British Columbia (82F/4E). Geological Fieldwork 1990, Paper 1991-1, B.C. Ministry of Energy, Mines and Petroleum Resources, p. 21-31.

Irwin, W.P. 1972. Terranes of the western Paleozoic and Triassic belt in the southern Klamath mountains, California. U.S. Geological Survey, Professional Paper 800-C, pp. C103-C111.

Jones, A.G. 1959. Vernon Map-area British Columbia. Geological Survey of Canada, Memoir 296, 186p.

Klepacki, D.W. 1983. Stratigraphic and Structural Relations of the Milford, Kaslo, and Slocan Groups, Roseberry Quadrangle, Lardeau Map Area, British Columbia. *In* Current Research, Part A. Geological Survey of Canada, pp. 229-233.

Klepacki, D.W., and Wheeler, J.O. 1985. Stratigraphic and structural relations of the Milford, Kaslo, and Slocan groups, Goat Range, Lardeau and Nelson map areas, British Columbia. *In* Current Research, Part A. Geological Survey of Canada, pp. 277-286.

Monger, J.W.H. 1977. Upper Paleozoic rocks of the western Canadian Cordillera and their bearing on Cordilleran Evolution. Canadian Journal of Earth Sciences, **14:**1832-1859.

Monger, J.W.H. 1985. Structural evolution of the southwestern Intermontane belt, Ashcroft and Hope map area, British Columbia. *In* Current Research, Part A. Geological Survey of Canada Paper 85 - 1A, pp. 349-358.

Monger, J.W.H 1989. Overview of Cordilleran geology. *In* Western Canada sedimentary basin; a case history. *Edited by* B.D. Ricketts. Canadian Society of Petroleum Geologists, Calgary, Alberta, Canada, pp. 9-32.

Monger, J.W.H. 1997. Plate tectonics and northern Cordilleran Geology: An unfinished revolution. Geoscience Canada, **24:**189:198.

Monger, J.W.H., Price, R.A., Tempelman-Kluit, D.J. 1982. Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera. Geology, **10**:70-75.

Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T., Struik, L.C., Campbell, R.B., Dodds, C.J., Gehrels, G.E., and O'Brian, J. 1991. Part B: Cordilleran terranes. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse, and C.J. Yorath. Geological Survey of Canada, no. 4, pp. 281-327. (also Geological Society of America, The Geology of North America, **G-2)**

Mortimer, N. 1986. Late Triassic, arc-related, potassic igneous rocks in the North American Cordillera. Geology, **14**:1035-1038.

Mortimer, N. 1987. The Nicola Group: Late Triassic and Early Jurassic subduction related volcanism in British Columbia. Canadian Journal of Earth Sciences, **4**:2521-2536.

Read, P.B., and Okulitch, A.V. 1977. The Triassic unconformity of south-central British Columbia. Canadian Journal of Earth Sciences. **14:** 606-638.

Roback, R.C. and Walker, N.W. 1995. Provenance, detrital zircon U-Pb geochronometry, and tectonic significance of Permian to Lower Triassic sandstone in southeastern Quesnellia, British Columbia and Washington. Geological Society of America Bulletin, **107**(6):665-675.

Souther, J.G., 1991. Volcanic regimes. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse, and C.J. Yorath. Geological Survey of Canada, no. 4, pp. 459-490. (also Geological Society of America, The Geology of North America, G-2)

Thompson, B., Mercier, E., and Roots, C. 1987. Extension and its influence on Canadian Cordilleran passive-margin evolution. *In* Continental Extensional Tectonics. *Edited by* M.P. Coward, J.F. Dewey and P.L. Hancock. Geological Society Special Publication No. 28, pp. 409-417.

Thompson, R.I., and Daughtry, K.L. 1996. New stratigraphic and tectonic interpretations, North Okanagan Valley, British Columbia. *In* Current Research 1996-A. Geological Survey of Canada, pp. 132-141.

Thompson, R.I., and Daughtry, K.L. 1997. Anatomy of the Neoproterozoic-Paleozoic continental margin, Vernon map-area, British Columbia. *In* Current Research 1997-A. Geological Survey of Canada, pp. 145-150.

Thompson, R.I., and Daughtry, K.L., 1998. Stratigraphic linkages across Vernon map area (82L), British Columbia. *In* Current Research 1998-A. Geological Survey of Canada, pp. 181-187.

Chapter 2

Geology of the Silver Star area, southeastern British Columbia: Implications for an early Jurassic link between the Quesnel "terrane" and ancestral North America

A version of this chapter is being prepared separately for submission to the Canadian Journal of Earth Sciences. A version of Figure 2-1 will be submitted to the Geological Survey of Canada, to be published as an Open File report.

Introduction

The contact between garnet- and higher-grade metamorphic rocks of mid- to late Paleozoic - early Mesozoic(?) age and lower-grade metamorphic rocks of late Paleozoic to Upper Triassic-early Jurassic(?) age is located in the Silver Star (Aberdeen) Mountain area, British Columbia (B.C.), Canada (Fig. 2-1). It is the proposed contact between accreted terranes and North American derived rocks in southeast B.C. (e.g. Coney 1980; Monger et al. 1982; Wheeler et al. 1991), i.e. the suture zone of the Cordilleran orogen, interpreted to have formed during the Jurassic by thrusting of allochthonous Quesnel terrane rocks over North American strata, with approximately 200 km of overlap (e.g. Ghosh 1995). This proposed fault has yet to be observed in the field. The contact has also been described as a discrete zone of extension that developed as a result of orogenic collapse during the Eocene, and juxtaposed low-grade and high-grade metamorphic rocks. It has been variably estimated to record between 30 and 90 km of displacement (Templeman-Kluit and Parkinson 1986; Bardoux 1993; Johnson 1994; Johnson and Brown 1996). A third interpretation describes the contact as an unconformity, requiring a North American origin for the low-grade strata, and negating the presence of a fault between the 'basement' and 'cover' rocks (Jones 1959; Read and Okulitch 1977; Klepacki 1983; Klepacki and Wheeler 1985; Höy and Andrew 1991; Roback and Walker 1995; Thompson and Daughtry 1996, 1997, 1998).

The main purpose of this investigation was to test the hypothesis that rocks in the Silver Star area, assigned to the Quesnel terrane (Quesnellia), stratigraphically overlie pericratonic North American rocks. This work formed part of the Geological Survey of

Canada's Ancient Pacific Margin NATMAP project. Six months of geological mapping at 1:20 000 scale were completed during the summers of 1998 and 1999, encompassing parts of BCGS TRIM maps 82L.025, 026, 035, 036, 045, and 046. The results are presented in Figure 2-1 (in pocket). Despite efforts to discover an area where this contact was exposed, the paucity of natural outcroppings, exhaustive drift cover, and vegetation made this impossible. The location of the contact was narrowed down to within several tens of meters on Silver Star Mountain and along Alderson Creek (Fig. 2-1). This study establishes a detailed stratigraphy for the area, provides interpretations of the structural, metamorphic, and plutonic history of the area, and provides further evidence suggesting a stratigraphic tie between rocks of the Quesnel terrane, and rocks of the ancestral North American margin.

Geologic Setting

Regional framework

The Canadian Cordillera is over 2000 km in length and 700 km in width (Fig. 2-2a), part of an orogenic belt that runs along the entire west coast of North America. The eastern limit is defined at the front of the Rocky Mountain fold and thrust belt, and the western limit by the edge of the North American plate. The orogen can be divided into five morphogeological belts, which are, from west to east, the Insular, Coast, Intermontane, Omineca, and Foreland belts (Fig. 2-2c, Gabrielse et al. 1991). This study is located in the southern portion of the Omineca belt, which, similar to the Coast belt, is characterized by igneous and metamorphic assemblages (Fig. 2-2c). The Omineca and Coast belts were originally interpreted to be the result of subduction producing an Andean-type magmatic arc, (Armstrong 1988, and references therein), but they have subsequently been reinterpreted as a continent-continent style collision zone, formed when the North American craton collided with the Intermontane and Insular superterranes (Terrane I and II of Monger et al. 1982) during the Jurassic and Cretaceous times, respectively (Fig. 2-2c; Monger et al. 1982; Gabrielse et al. 1991; Monger 1997).

The Cordillera has been divided into terranes, defined as fault bounded slices of crust preserving an internally consistent geologic record, and distinct from neighboring

terranes (Irwin 1972). It was subsequently recognized that some of these terranes may have originated far from their present locations, and the term "suspect terrane" was applied (Coney 1980). In the southern Omineca Belt, the easternmost of these is the Quesnel terrane, described as a Late Triassic to Early Jurassic intra-oceanic arc that developed, in places, above Ordovician to Triassic rocks of arc and oceanic affinity (Monger 1977, 1985; Mortimer 1986, 1987; Gabrielse et al. 1991; Monger et al. 1982, 1991; Souther 1991; Dostal et al. 2001). This arc system includes the Nicola, Slocan, Ymir, and Rossland groups in southern B.C. The "basement" to the Quesnel terrane is divided into the Harper Ranch and Okanagan subterranes (Monger 1977, 1985; Monger et al. 1982, 1991; Mortimer 1987; Gabrielse et al. 1991; Souther 1991; Dostal et al. 2001).

The suspect nature of the Quesnel terrane was based on the presence of Tethyan and mixed Tethyan-Boreal fauna, which led to the inference that the Quesnel arc developed off shore, a minimum of 500 km south of its current latitude (e.g. Taylor et al. 1984; Carter et al. 1991). Paleomagnetic data have been used to interpret latitudinal displacements in excess of 2400 km (e.g. Symons 1983; Irving et al. 1985; Rees et al. 1985; Symons 1985). Radio-isotope studies of the Upper Triassic Nicola Group volcanic rocks of the Quesnel terrane, which show no evidence for contamination from underlying continental crust, have been used to propose an allochthonous, intra-oceanic, origin for the Quesnel terrane (Smith et al. 1995; Armstrong 1988). In contrast, U-Pb zircon geochronology from igneous units of the Quesnel terrane in the Kootenay Arc region (Fig. 2-2b), including volcanic tuffs from the upper Elise Formation (late Sinemurian to early Toarcian) and the 200 Ma Lexington porphyry, show evidence of inheritance from Proterozoic crust (Höy and Dunne 1997; Dostal et al. 2001). Interaction with continental crust in eastern parts of the Quesnel terrane, within the Omineca belt, is also suggested by $^{87}Sr/^{86}Sr_i$ ratios > 0.704 for Mesozoic igneous rocks, increasing eastward to values between 0.705 and 0.707 in the Kootenay Arc region (Fig. 2-2b; Armstrong 1988). Nd isotope and trace element geochemistry of metasedimentary rocks flanking the east side of the Upper Triassic Quesnel arc give εNd_T values between –9.1 and +5.6, La/Sc ratios between 0.38 and 4.76, and Eu anomalies between 0.6 and 1.0

(Unterschutz et al. 2002), suggesting derivation, in part, from a proximal source with the geochemical characteristics of evolved continental crust. The most compelling evidence in favour of an allochthonous interpretation for the Quesnel terrane was a geochemical study of igneous rocks in southeast British Columbia by Ghosh (1995), which showed an apparent increase in crustal contamination in igneous rocks in mid-Jurassic time, and was used to propose the onset of obduction at that time. However, Unterschutz et al. (2002) demonstrated that the data do not necessarily indicate a change of basement character, but, alternatively may show increasing degrees of crustal contamination toward the craton since the late Paleozoic. The Quesnel terrane may have developed on easterly thickening crust of the North American margin.

Unconformable relationships between Quesnel terrane strata and rocks of ancestral North America have been described throughout southeast B.C. (Jones 1959; Read and Okulitch 1977; Klepacki 1983; Klepacki and Wheeler 1985; Höy and Andrew 1991; and Thompson and Daughtry 1998). The most compelling evidence comes from approximately 75 km northwest of Nelson, in the Kootenay Arc region (Fig. 2-2b, d), where Upper Triassic rocks of the Slocan Group, of the Quesnel terrane, lie unconformably on rocks that are tied to the North American miogeocline (Klepacki 1983; Klepacki and Wheeler 1985).

The present study is of an area near Vernon B.C. (Figs. 2-1, 2-2), approximately 150 km west of the Kootenay Arc. As in the Kootenay Arc, on Silver Star Mountain, pericratonic North American rocks (Kootenay terrane, Fig. 2-2d) are in contact with rocks of the Quesnel terrane (Fig. 2-2d). These pericratonic rocks are part of the Mount Ida Group (Jones 1959), and include the Silver Creek Formation, and possible equivalents of the Tsalkom, Sicamous, Eagle Bay and Chapperon successions. Regionally, rocks of the Mount Ida Group have been interpreted to sit in the hanging wall of the Eagle River-Okanagan Valley fault, the local expression of low-angle extensional faults that would juxtapose low-grade rocks with high-grade rocks (Fig. 2-2d; e.g. Templeman-Kluit and Parkinson 1986; Johnson 1994; Johnson and Brown 1996). Although Paleozoic units are correlated with the Mount Ida Group in this study, their high-grade nature has led to previous correlations with possible equivalents in the footwall of the Eagle River-

Okanagan Valley fault, the Hunters Range Assemblage of the Shuswap Complex (Johnson 1994; Thompson and Daughtry 1996). Overlying the Mount Ida Group in the study area are rocks currently interpreted to be allochthonous, assigned to the Quesnel terrane, including possible equivalents of the Harper Ranch and Okanagan subterranes, as well as the Slocan, Nicola, Ymir, and Rossland groups, and the Ashcroft Formation.

Previous Mapping

The first geological map including the study area was published by Dawson (1898). Dawson recognized four units in the Vernon area; an Archean Shuswap series, the Cambrian Nisconolith series, the Carboniferous Cache Creek formation, and Miocene basalts. He noticed that the Nisconolith series, now a part of the Upper Triassic succession of the Quesnel terrane, appeared to be deposited upon an irregular surface and thus varied greatly in thickness across the mapped area. This was followed by a geological map and report by Daly in 1915. In 1959, Jones published a geological map and report on Vernon map area (82L, Fig. 2-2d), at a scale of four miles to one inch (1:253 440). Jones recognized several unconformities within the study area, at least one of which is pre-Triassic (Read and Okulitch 1977). Read and Okulitch (1977) recognized a highly irregular surface upon which Triassic rocks were deposited, in some places overlying rocks of the Harper Ranch or Okanagan subterranes, and in others rocks of North American affinity. The study area was later included in a regional compilation at 1:250 000 scale by Okulitch (1979). Most recently, Thompson and Daughtry (1996, 1997, 1998) reported on studies within the Vernon map area (Fig. 2-2c) that describe the possibility of an unconformable relationship between Quesnel terrane strata and North America.

Geology

Layered Units

The following represents descriptions of units mapped within the study area (Fig. 2-1). Nowhere within the field area was a complete section for any unit observable. Showing a constant thickness for units across the field area on the map is likely an

oversimplification, considering that these rocks are heterogeneously strained (see Structural Geology section below).

Pgn

Pgn outcrops in one area along the eastern boundary of the map area, in the Trinity Valley (Fig. 2-1). This unit is a pelitic paragneiss of uncertain age and affinity, and is interpreted to be the oldest unit within the study area. The contact between Pgn and overlying units was not observed in the field, nor was the basal contact, thus leaving the thickness of Pgn unknown. Possible correlatives include similar gneissic rocks to the north and east within the Shuswap Complex, and lacking any better constraints, a Proterozoic age is assigned.

Dcq (Chase Formation)

Dcq outcrops in three areas of the map, along Fortune and South Fortune Creek, northeast of Vernon along B.X. Creek, and north of Lumby near Gallon Creek (Fig. 2-1). Dcq is a calcareous quartzite to siliceous marble, with lesser amounts of carbonaceous argillite and metasiltstone. Grain size varies within layers from fine to coarse. Rarely, metamorphic minerals including diopside and tremolite are present, variable from mm to several cm in length. Fresh surfaces vary in colour from white to blue-grey. The most striking feature of this unit is the differential weathering pattern visible on weathered surfaces, due to the preferential weathering out of calcite, leaving quartz crystals and quartz-rich layers protruding and creating a distinctly pitted surface (Plate 2-1b). This unit commonly contains greater than 50% intrusive granitic and pegmatitic material, in the form of sills and dykes. These intrusions were named the Silver Star Intrusions by Jones (1959), and are described in more detail under the section on Igneous Units below. In the Fortune Creek area, Dcq preserves a high degree of strain and is, in places, augen gneiss. Intrusive material from this locality, when viewed in thin section, shows protomylonitic fabric, with feldspar porphyroclasts that are relatively rigid and form augen in a finer grained foliated matrix. The basal contact of Dcq was not observed in the study area, leaving its thickness unknown.

Dcq is correlative with unit Pc of Glombick et al. (2000), of inferred Late Proterozoic – (?) Early Paleozoic age, that outcrops just south of the study area along

Kalamalka lake, the Devonian Cqm in Vernon and Lardeau map areas (R.I. Thompson, personal communication, 2001), and the Chase Quartzite (Chase Formation, Jones 1959; Campbell and Okulitch 1973). A Devonian age was established for the Chase Formation based on the analysis of two concordant detrital zircons with $^{207}Pb/^{206}Pb$ ages of 405 ± 13 and 424 ± 13 Ma (Thompson et al. 2002), and the age of the cross-cutting 365.9 ± 2.7 Ma granodiorite unit Dg (U-Pb zircon, Slemko 2000). The Chase Formation outcrops along strike, across the Okanagan Valley, 11 km northwest of the Dcq locality in Fortune Creek (Jones 1959). Campbell and Okulitch (1973) mapped the Chase Formation as a member of Pba (Silver Creek Formation, see below).

Pgr

Pgr is a greenstone unit that outcrops in three places in the northeastern portion of the study area (Fig. 2-1), where it has been completely altered to fine-grained chlorite and sericite. Pgr may be a distinct lithologic unit, a facies change within unit Pba (see below, Fig. 2-1), or simply be a more altered layer of mafic rock within Pba (see below). If these rocks are not part of unit Pba (see below), possible correlative rocks in the region include the Tsalkom and Sicamous Formations or the Eagle Bay Group. Only three outcrops of this unit were observed, leaving the geologic significance of this unit unresolved by present work.

Pba (Silver Creek Formation)

Pba outcrops throughout the study area; in the northernmost portion of the map, at the base of Fortune Creek, on Silver Star Mountain, along the Trinity Valley, and just north of Lavington (Fig. 2-1). This unit consists of medium- to coarse-grained biotite- and/or amphibole-rich quartzofeldspathic schist and amphibolite, with lesser amounts of marble, micaceous quartzite, and calc-silicate schist. Metamorphic minerals in pelitic layers variably include K-feldspar, sillimanite, kyanite, staurolite, garnet, biotite and muscovite, while amphibole is characteristic of amphibolite units, and diopside, garnet, and tremolite of calc-silicate units. Rusty alteration often coats weathered surfaces. Similar to Dcq, Pba also commonly contains over 50% intrusive material in the form of granitic and pegmatitic dykes and sills. This material was designated the Silver Star

Intrusions by Jones (1959), and is described below under the Igneous Units section. Pba is estimated to be 600 m thick above unit Dcq, from projected map relations (Fig. 2-1).

Pba overlies Dcq, and although the contact was not observed, it can be defined within tens of meters along Fortune Creek, and South Fortune Creek (Fig. 2-1). There is no change in fabric orientation or metamorphic grade across this boundary, and the contact is inferred to be stratigraphic and conformable. This is similar to relationships described by Jones (1959) and Campbell and Okulitch (1973) between the Chase Formation and the Silver Creek Formation, to which Dcq and Pba are correlated, respectively, based on lithologic similarities and relative stratigraphic position.

The age of Pba is inferred to be Devonian, based on correlation with the Silver Creek Formation. The age of underlying Dcq (see Dcq above) places a maximum age on Pba to be Devonian. To the north near Sicamous, Slemko (2000) mapped Dg (365.9 ± 2.7 Ma granodiorite) to cut early (?) Paleozoic Eagle Bay Formation rocks, and described the Silver Creek Formation (Pba) to be stratigraphically overlain by the early (?) Paleozoic Sicamous Formation, in turn overlain by the Eagle Bay Formation. To the northwest, the Devonian Little Shuswap Gneiss cuts the Silver Creek Formation (Pba; personal communication from R. Friedman and A.V. Okulitch to N. Slemko, Slemko 2000).

Pcs

Pcs outcrops in three locations within the study area; in the north along Joyce Creek, on Silver Star Mountain, and on Vernon Hill (Fig. 2-1). Pcs consists of carbonaceous pelitic to semi-pelitic phyllite and schist, with lesser amounts of calcareous slate, micaceous and/or pyritic quartzite, and calc-silicate schist. Units vary in grain size from fine to coarse, and in colour from black to grey to blue-grey. Locally, compositional layering, and more rarely transposed bedding features including grading, cross-bedding, truncation, and flame structures, are preserved within layers that vary from mm to cm in thickness. In the northern portion of the study area, unit Pcsl, a distinctive black calcareous slate within unit Pcs, was mapped over a strike distance > 3 km. Pcs is characterized by the presence of some or all of the following metamorphic porphyroblasts: staurolite, kyanite, garnet, plagioclase, biotite and muscovite (Plates 2-1c,

2-6a), which give a characteristic knotted appearance to the rock. On weathered surfaces, Fe-rich porphyroblasts and pyrite are often rusty in colour, or can be completely weathered out leaving a rusty residue. This weathering out may be facilitated by retrograde metamorphism of metamorphic minerals to chlorite and sericite, visible in thin sections of unweathered samples. Granitic and pegmatitic material of the same character that pervades unit Pba is present within Pcs, but in diminished quantity, comprising 10 to 20% of the succession near the base, decreasing upward to 0%.

The contact between Pcs and Pba appears to be conformable, and in fact may be a transitional depositional contact, as suggested by Unterschutz et al. (1999) near Sovereign Lake on Silver Star Mountain. There, an approximately 100 m thick zone in which interlayered rocks could be assigned to either the overlying or underlying successions is well exposed. This could be consistent with a transitional depositional contact, or with tectonic juxtaposition, but a stratigraphic contact is favoured based on the continuity of fabric and metamorphic grade across this zone, and a lack of systematic repetition of units such as might be expected in isoclinal folding. The Pcs-Pba contact is drawn at the base of this transitional zone, which marks the last occurrence of sillimanite-bearing schist within unit Pba. Although a continuous section of Pcs is not observable within the field area, down plunge projection suggests a maximum thickness of 1 km (Fig. 2-1).

Psc (Spa Creek Assemblage)

Psc outcrops in the northern portion of the map area, east of Kendry Creek (Fig. 2-1). Psc consists of marble, stretched quartzite cobble metaconglomerate, biotite- and/or amphibole-rich schist, chloritic schist, and intermediate to felsic tuffaceous, ignimbritic, and porphyritic metavolcanic rocks. This succession contains two lithologically distinct mappable units that have proved to be good marker horizons for defining structures within the area (Fig. 2-1). The lowermost of these is unit Psccgl, a stretched and flattened quartzite cobble metaconglomerate, interpreted to form the base of Psc, and in which cobbles are stretched and flattened to current length:width:height ratios between 5:2:1 and 10:2:1 (Plate 2-1d). These stretched cobbles define an east-northeast plunging shape lineation (Fig. 2-1), and indicate strain within these rocks. Metamorphic porphyroblasts of garnet statically overgrow foliation in this unit, on average between

0.25 and 1 cm in diameter, and are more resistant to weathering than the host rock (Plate 2-1d). The second marker horizon is PSCmb, a foliated, white to grey and white banded, coarsely crystalline marble unit. This coloured banding is visible at thicknesses varying from 1 cm to greater than 10 m. This unit forms resistant ridges in an area that is topographically flat (Fig. 2-1), which makes it an excellent marker horizon for mapping purposes (Plate 2-2a). PSCmb varies in thickness between approximately 50 and 100 m.

Within PSC are intermediate to felsic tuffaceous, ignimbritic, and porphyritic metavolcanic units that vary in colour from dark to light grey, and which can be massive or foliated depending on the absence or presence of orientable minerals. The ignimbrite units often contain fine-grained clasts that are difficult to identify, but one of the more felsic layers with a biotite- and amphibole-rich matrix contains larger flattened clasts of quartzite and fine-grained volcanic rocks, approximately 1-3 cm long and 0.5 cm thick, aligned in the foliation. A distinctive intermediate biotite-rich porphyry unit with aggregates of chlorite and interbedded layers of amphibole-rich schist is also present. Another distinctive volcanic unit is characterized by the presence of metamorphic bow-tie amphiboles that can reach several cm in length. These volcanic units vary in thickness from > 50m to a scale of tens of cm where they are interlayered with sedimentary units, which include pelitic to semi-pelitic schist and phyllite. On weathered surfaces, these rocks can have a distinctive brown to rusty coloured coating.

Retrograde metamorphism affects PSC, in some places resulting in complete replacement of original minerals by chlorite, biotite, and sericite. The top of unit PSC is not seen, but plunge projection suggests a minimum thickness of 400 m.

PSC is interpreted to unconformably overlie unit Pcs, forming the uppermost unit in what appears to be an upright section northward from Fortune Creek (Fig. 2-1). Based on lithological similarities and relative stratigraphic positions, this unit is correlated with the Spa Creek Assemblage of Erdmer et al. (2001). East of Kendry Creek is the only area where unit PSC is present, suggesting that these rocks may represent a localized volcanic environment or, more likely, based on the correlation of these rocks westward across the Okanagan Valley to localities near Glenemma and Spa Creek (see Fig. 2 of Erdmer et al. 2001), they were eroded or tectonically removed from their position in the stratigraphic

sequence (possibilities are discussed below). To the south, on Vernon Hill, units Pmv and Pccs (below) may represent distal equivalents to unit Psc. An unconformable basal contact between Psc and Pcs is suggested by the presence of the stretched quartzite cobble metaconglomerate, Psccgl. Read and Okulitch (1977) interpreted this conglomerate to be the basal Triassic conglomerate of their regional sub-Triassic unconformity, and correlated this succession with the Glenemma and Spa Creek localities. Age constraints for this unit remain poor, but U-Pb geochronology from Erdmer et al. (2001) reveals a maximum age for the conglomerate to be 555.6 ± 2.5 Ma. Further constraints are provided by the age of the underlying unit Dcq, indicating a Devonian or younger age for these rocks. Psc is overlain by late Triassic – early Jurassic (?) rocks of unit Ms (see below), providing a minimum age for Psc.

Pmv

Pmv outcrops in the southern portion of the map area, on Vernon Hill (Fig. 2-1). This unit consists of intermediate to mafic metavolcanic rocks including biotite and/or actinolite schist, amphibolite, carbonaceous argillite, metasiltstone, metasandstone, and calc-silicate schist. Sedimentary units vary in colour from blue-grey to grey to brown. Static metamorphic porphyroblasts overprint regional fabric and include garnet, amphibole and biotite, some of which are now retrograded to biotite and chlorite. Sills and dykes of Jgtd (see below) are common within Pmv. The thickness of this unit remains unknown, but is > 500 m on Vernon Hill.

Pmv overlies unit Pcs on Vernon Hill (Fig. 2-1), and along with unit Pccs may represent distal equivalents of the Psc. Based on lithologic similarities, these units may also correlate with the Chapperon Group (Daughtry et al. 2000). The basal contact of Pmv was not observed, but is interpreted to be conformable, based largely on the continuity of fabric across this contact. However, some evidence exists that may support a fault contact between these units, and this possibility is discussed in the Structure section.

Pccs

Pccs outcrops in the southern portion of the map area, on Vernon Hill (Fig. 2-1). This unit consists of carbonaceous and calcareous metasiltstone and metasandstone,

varying in colour from blue-grey, to grey, to white. Layer parallel sills of granitic material, with thicknesses of a few mm to cm are folded along with compositional layering. These rocks are cut by patchy occurrences of granitic pegmatite, and dykes of unit Esp (see below). The thickness of this unit is unknown, but is approximately 200 m on Vernon Hill.

Unit Pccs overlies unit Pmv. This contact is not observed, but is inferred to be unconformable, marked by the occurrence of a sedimentary breccia, with a very fine-grained carbonaceous matrix and randomly oriented clasts, at the base of this contact. This contact was first suggested as unconformable by Jones (1959), which he termed the Lavington unconformity, although his interpretation regarding surrounding geology differed greatly from that presented here. Jones' interpretation would correlate unit Pccs with Carboniferous (?) and Permian Cache Creek Group rocks, and unit Pmv with Monashee Group rocks, which he inferred to be Precambrian. More age constraints are now available, and unit Pccs is inferred to be Paleozoic, with a maximum Devonian age indicated by the underlying unit Pba, and, like unit Pmv, may be a distal equivalent to unit PSC in the northern portion of the map area (Fig. 2-1).

Pccs is characterized by tight to isoclinally folded strata (Plate 2-1e). Compositional layering is distinct in these units, defined by colour and grain size, and appears unfolded when viewed from two-dimensional outcrops on the hilltops, due to the upright nature of these folds. Only in cliff exposures is the high degree of shortening apparent.

PHRmv (Harper Ranch Group)

PHRmv outcrops in the southern portion of the map area, northeast of Lavington (Fig. 2-1). PHRmv is a succession of intermediate metatuffaceous rocks, usually a characteristic mint-green colour, white marble, black to grey layered marble, dark grey carbonaceous argillite and blue-grey, to grey, to white metasiltstone. The distinctive white marble beds are interlayered with other units, but become the dominant lithology at the top of this succession where they are greater than 10 m in thickness. This suggests a transition from an active volcanic regime to a quiescent one that would permit reef

growth. The basal contact of this unit is not seen. PHRmv underlies rocks of the Ms (see below) succession.

Based on lithologic similarities, these rocks are correlated with the Harper Ranch Group, currently considered the basement, in places, to the Quesnel terrane (Monger 1977, 1985; Monger et al. 1982, 1991; Mortimer 1987; Gabrielse et al. 1991; Souther 1991). Wheeler and McFeely (1991) made this correlation in the study area (Fig. 2-2d). Fossils, including Crinoid fragments, a Productid fragment, and fragments of corals within comparable marbles approximately 2 km to the south across the Coldstream Valley (Fig. 2-1) suggest a Permian age for these rocks (F-8 locality of Jones 1959, identified by P. Harker, 1951).

PHRmb (Harper Ranch Group)

PHRmb outcrops on the north side of the Coldstream Valley (Fig. 2-1) and consists of massive white to blue-grey marble that forms resistant cliffs. These rocks are indistinguishable from the upper marbles in unit PHRmv, but are not interlayered with volcanic rocks at this location. These units are assigned a Permian age based on the presence of disarticulated Crinoid stems (location 98 JU 323, Appendix 2-1), fragments also observed in the F-8 locality of Jones (1959, see details above).

Ms (Quesnel "terrane")

Ms outcrops throughout the study area (Fig. 2-1). This unit consists of black, to blue-grey, to white carbonaceous and calcareous argillite, slate, metasiltstone, and metasandstone, with lesser metaconglomerate, grey to white marble, and green augite porphyry. The sedimentary rocks preserve fine laminations in some areas, but layers are usually cm to tens of cm thick, and primary features such as cross-bedding, grading, flame structures, microfossils, and trace fossil borings are often preserved (Plate 2-2c). R.I. Thompson (unpublished data, personal communication 2001) identified two localities of Upper Triassic fossils north of Lavington, identifying time-equivalent deposits to the Slocan, Nicola, and Ymir groups in this region. Upper Triassic conodonts were also discovered in lithologically identical rocks, 15 km east of Lavington (Okulitch and Cameron 1976). Unit Ms varies in metamorphic grade from rare occurrences of garnet-grade rocks near the base, upward to biotite- and then chlorite-grade rocks.

Two marker units occur within unit Ms. These include Maug and Mcgl. Maug is a green augite porphyry. In the Silver Star area this unit is conformable with regional schistosity (Fig. 2-1). Small dykes of Maug cut stratigraphy locally near the large area of Maug in the Trinity Valley, and isolated outcrops occur lower in the succession within Ms, Pccs, and Pcs. These could be feeder dykes to the flow, or they may indicate a cross-cutting relationship between Maug and Ms. Although some outcroppings of Maug are massive, others are foliated, and in places folded (Plate 2-2b) with surrounding sedimentary units of Ms, which lends support to the interpretation of Maug as a primary element within the Ms succession, as it is inferred to be in this study. Augite porphyry is found both in Upper Triassic rocks of the Nicola Group to the west, and in Early Jurassic Rossland Group rocks to the east (Preto 1977; Preto et al. 1979; Monger 1985; Höy and Dunne 1997).

Mcgl is a metaconglomerate on Silver Star Mountain that varies from matrix- to clast-supported, with flattened sub-angular to sub-rounded clasts of dominantly limestone and marble, with lesser amounts of quartzite, schist, plagioclase porphyry and granite(?) clasts, of pebble to cobble size (4 mm to 256 mm; Plate 2-3a, b). At least four interbeds of Mcgl occur on Silver Star Mountain, two of which were mappable over distances between 0.5 and 1 km (Fig 2-1). These are interpreted as separate beds and not as folds of the same layer because each layer differs slightly from one another in overall clast size, shape and matrix character. Similar conglomerate units occur at other locations within the mapped area (Table 2-1), and may be correlative, but these could not be tracked over any distance and thus do not appear on the map. These conglomerates vary from matrix to clast-supported, with a variation in clast size at different locations from a few mm to 15 cm in length, but on average were between 1 and 4 cm in length (see Table 2-1 for descriptions, Plate 2-3d, e, f).

A maximum age of 182.6 ± 4.2 Ma or 192 ± 3 Ma for Mcgl on Silver Star Mountain is interpreted from U-Pb detrital zircon geochronology from a whole-rock sample (Fig. 2-4b, c, see Geochronology section). Although it remains possible that this age may be metamorphic in nature, an igneous origin for these zircons appears most likely based on the low metamorphic grade of the strata, and the fact that several of the zircons are

concordant (see below). If these zircons are metamorphic, then the maximum age of these rocks is known from a poorly preserved fusulinid within a limestone clast in this unit, determined by L. Rui (personal communication, 1999) to be most likely Permian in age, but possibly Pennsylvanian (Plate 2-3c). A Pennsylvanian(?)-Permian age for limestone clasts would be consistent with derivation from nearby PHR strata.

Interpreting the zircons within this unit to be detrital suggests that the uppermost strata on Silver Star Mountain are of early Jurassic age or younger. This interpretation suggests that Quesnel arc deposition may have continued from late Triassic time into early Jurassic in the Silver Star area, and that strata of early Jurassic age may be more widespread throughout the southern Cordillera than previously thought. Potential source rocks for these zircons are not known within the local area, nor are they common within the Cordillera, but possibilities exist in the Kootenay Arc region to the east, and to the west in the Quesnel volcanic arc (see Geochronology section for details).

The total thickness of Ms remains unknown, but it reaches approximately 500 m on Silver Star Mountain (Fig. 2-1). If Mcgl on Silver Star Mountain represents the base of an early Jurassic succession, then the underlying Triassic sequence would be no thicker than 300 m.

The most striking feature of unit Ms is that it sits atop every older unit in the area except Pgn, Pmv, and Pccs (Fig. 2-1). On Silver Star Mountain, Ms truncates underlying unit Pcs, which outcrops beneath it to the west, but is missing from the stratigraphic section to the north, south, and east where Ms overlies Pba. Along Fortune Creek, Ms overlies unit Dcq, indicating Pba is missing from the stratigraphic sequence there. Based on the fact that unit Ms overlies several older units in the area, and appears to cut down through stratigraphy to the north, south, and east, an unconformable basal contact is inferred. Alternative interpretations include a structural contact, with truncation of several underlying units a factor of the pre-faulting structure of units in the footwall. Unconformable relationships in the study area were first suggested by Jones (1959). Read and Okulitch (1977) also interpreted a sub-Triassic unconformity in the study area, and throughout southeast B.C.

Evvs

Evvs outcrops just north of Lavington in the Coldstream Valley (Fig. 2-1). This unit consists of andesite, dacite, and rhyolite with lesser pyroclastic and epiclastic flows, volcanic breccia, and volcaniclastic and clastic sediments including breccia and conglomerate (see below: Esbr, Ecgl). Eocene rocks cut and sit atop nearly every other lithology where they outcrop on the north side of the Coldstream Valley (Fig. 2-1). A cross-cutting relationship between a pyroclastic volcanic breccia and Ms can be observed on a road cut between Lavington and Becker Lake, and is interpreted as a volcanic vent (location 99 JU 15, Appendix 2-1; Fig. 2-1). Bedding in the volcaniclastic successions north of Lavington is graded in places. Interbedded volcanic rocks are a characteristic grey-green colour, fine-grained, and commonly have calcite and/or quartz veins. Alteration to chlorite and epidote makes primary mineralogy difficult to discern, but vestiges of primary plagioclase are common, visible in thin section. Pyroclastic flows occur in succession from the base of the valley 4 km north of Lavington, upward in succession to the northeast, and to the east where they are capped by Miocene basalts (Mab, see below; Fig. 2-1). Some of these units have a distinct epidote green colour to matrix or clast, likely a result of alteration by hydrothermal or deuteric fluids, with phenocrysts of amphibole and pyrite in both. Matrix mineralogy is often almost completely altered to chlorite, epidote and/or sericite, and in some samples a devitrified matrix is epidotized, but relict hornblende and plagioclase can be identified in thin sections of less altered rocks. Successive flows contain angular fragments from underlying flows. The flows dip steeply, which may reflect a steep original topography, and/or structural rotation that occurred subsequent to deposition. Based on lithologic similarities, these rocks are correlated with the Eocene Kamloops Group, similar to interpretations of Jones (1959) and Okulitch (1974).

Esbr and Ecgl

These two units outcrop in the south-central portion of the map area along the Coldstream Valley (Fig. 2-1). They occur in greatest abundance in a graben, northeast of Lavington, which is approximately 1 km in width and nearly 3 km in length (Fig. 2-1). Esbr is a heterolithic sedimentary breccia unit that contains angular fragments of dark

grey carbonaceous metasedimentary rock, volcanic rocks, coal, granite, marble and slate (Plate 2-2d). Ecgl contains rounded clasts of black argillite, slate, marble and volcanic rocks. The variety of clasts increases upward in the graben succession. Clasts in both vary in diameter from mm to 30 cm, but have a bimodal size distribution, with estimated means around 1.5 and 5 cm. Potential sources of these clasts can be found in surrounding rock units, including the pyroclastic volcanic units of Evvs. Similar units occur directly south of the mapped area on Bluenose Mountain (Ekc of Glombick 2000).

Mab

Mab outcrops approximately 4 km northeast of Lavington in the Coldstream Valley. Mab are amygdaloidal and vesicular basalt flows, with olivine and plagioclase phenocrysts. Some flows may be intermediate in composition, based on their slightly lighter colour. One vesicular flow contained entrained clasts of non-vessicular, fine-grained rock that were small and difficult to identify. A possible feeder dyke was found in the northern most outcrops of Mab (99 JU 428 and 429, Appendix 2-1; Fig. 2-1), which was a massive, black-grey, non-vesicular rock with clasts of vesicular rock within. Alternatively, this could be the base of an overlying basalt flow that incorporated clasts from the top of an underlying flow. These basalts are correlated with the Miocene basalts mapped directly south of the Coldstream Valley (Fig. 2-1) by Church and Suesser (1983).

Igneous Units

Silver Star Intrusions

Jones (1959) termed the abundant granite and pegmatite that pervades units Dcq and Pba (> 50% of rock unit), and is less abundant in Pcs (< 20%), the Silver Star Intrusions. These intrusions could not be mapped separately from the lithologic units they intrude because of their near ubiquitous presence within them throughout the field area. The intrusions vary from granite to tonalite in composition, and from aplite to pegmatite in grain size. The majority of these are sills and lenses, concordant with planes of foliation and compositional layering, and with thicknesses between mm and tens of cm. However, dykes and larger masses >10 m in thickness also occur. It is likely that several intrusive phases are present. A single outcrop in the northern portion of the map

area (98 JU 77, Appendix 2-1) reveals relationships between some phases that contain relict magmatic epidote. At this outcrop, the host rock of amphibole schist is cut by granodiorite, which is in turn cut by a biotite-bearing aplite, cut by pegmatite. Quartz veins in this outcrop are cut by both pegmatite phases. This is the only outcrop at which epidote was observed. The presence of magmatic epidote in granitic magmas has been interpreted to indicate an origin deep in the crust, with a rapid ascent rate to prevent complete resorption of the mineral (Brandon et al. 1996).

In other areas, granodiorite cuts pegmatite, indicating that multiple phases of magmatism may have occurred, or that all phases are broadly contemporaneous. Although some outcrops of these intrusions are massive, others are foliated, which suggests emplacement was pre-, syn- and post-tectonic, as was first suggested by Jones (1959). Accessory minerals within granitic units are variable, but include biotite, muscovite, garnet, tourmaline, and zircon. Pegmatite phases can consist solely of feldspar and quartz, or contain accessory minerals including muscovite, biotite, tourmaline, diopside, garnet, and amphibole. No direct age constraints for these units exist. Attempts to date a muscovite tonalite unit that cuts unit Pcs on Silver Star Mountain were unsuccessful.

Nd analysis of a sample from near Sovereign Lake (Fig. 2-1, 00 JU 02) is consistent with an *in-situ* origin for these melts, which is consistent with the high metamorphic grade of rocks near the base of Pba on Silver Star Mountain (see below).

Ptum

Ptum intrudes unit Pba in the northeastern portion of the map area (Fig. 2-1). This unit is a talc-rich chromite-bearing serpentinite. In places it is almost entirely altered to serpentine, but in some outcrops original mineralogy is discernable, and thin section examination shows the presence of talc, tremolite, and calcite, with possible epidote, olivine and anthophyllite. Prior to alteration, this rock was likely peridotite, and is interpreted to be intrusive and to correlate with the Old Dave intrusions described by Jones (1959). Contact relationships were not observed.

Jgtd

Jgtd outcrops in two locations along the Coldstream Valley in the southern portion of the map area (Fig. 2-1). Jgtd is a medium- to coarse-grained granite to granodiorite that contains variable amounts of biotite (0 to 20%), muscovite (0 to 10%), garnet (0 to 5%), and zircon (accessory). In places, quartz and feldspar define a rodding lineation. Jgtd cuts Pmv and Pcs on Vernon Hill. U-Pb zircon dating yielded a date of 145 ± 4 Ma for a sample from the southwest side of Vernon Hill (Fig. 2-1, Fig. 2-3, see Geochronology section).

Jgtd on Vernon Hill is correlated with a lithologically similar pluton outcropping 10 km to the east along the Coldstream Valley (Fig. 2-1). In this eastern area, Jgtd is cut off by an Eocene normal fault, and is interpreted to cut units Ms and Pba.

?peg

?peg outcrops as a mappable unit for over 4 km in the northern portion of the map area, and is a biotite and/or muscovite ± garnet granitic pegmatite body (Fig. 2-1). It cuts unit Pba. Pegmatite is present throughout unit Pba, but there is likely more than one phase (see section Pba above).

Esp

Esp outcrops over mappable extents along the Coldstream Valley on Vernon Hill, north of Lavington, and east of Lumby (Fig. 2-1). Esp consists of porphyry dykes that are variably dominated by K-feldspar, plagioclase, or biotite, and which cut nearly every other unit in the field area. A "salt and pepper", or specked black and white, appearance is characteristic of these dykes. They are massive, except locally where brittle faulting has taken place and they show slickenside fabric. On Vernon Hill, entrained clasts of foliated granite are found within (Plate 2-2e). An Eocene age is assumed based on the lack of penetrative foliation and entrainment of foliated granite clasts, indicating emplacement after the latest phase of deformation, as well as on cross-cutting relationships observed with all older units except Pgn, Dcq and Psc.

Structural Geology

Rocks in the study area have undergone multiple phases of deformation, evident at scales from the microscopic to map scale. Mesozoic and older layered lithological units are penetratively deformed, and have been subjected to at least four phases of deformation (D_1 - D_4). Strain is heterogeneously distributed.

Folding (see Fig. 2-1)

Shallow northwest plunging box-like folds, with amplitudes of ~150 m and wavelengths > 1 km, are defined within Psc by the white and grey striped marble marker member (Pscmb) and quartzite cobble conglomerate (Pscclg) member (Fig. 2-1). These folds are also outlined in the surface trace of unit Pcsl, a distinctive black calcareous slate within the carbonaceous phyllite and schist succession (Pcs)(Fig. 2-1). On the basis of stratigraphic continuity upward from Fortune Creek, these folds are interpreted to be plunging gently northwest and verging southwest. A reversal of schistosity is also apparent in unit Pba, directly north of where Psc outcrops, and may indicate the continuation of this fold northward (Fig. 2-1). Pre- Upper Triassic deformation (pre-D_1) was interpreted from Spa Creek Assemblage (Psc) rocks directly west of the study area (Erdmer et al. 2001), however the present study could not substantiate or disprove this. These folds are inferred to result from D_2 deformation, and to extend into the Upper Triassic succession (Fig. 2-1). Psc rocks show evidence of at least two phases of folding. D_2 deformation led to the development of a steep penetrative foliation within the rocks, inferred to be axial planar to these folds, that was folded during subsequent deformation (D_3, Fig. 2-5). Compositional layering is not well preserved in most units of Psc on the outcrop scale.

Late Triassic - early Jurassic rocks show evidence of three phases of shortening (D_1-D_3). The earliest (D_1) resulted in a layer parallel, or near-parallel, cleavage (S_1) that shows evidence of having been subsequently folded twice, in north-south and east-west directions, approximately orthogonal to one another (D_2 and D_3) (Plate 2-4a; Figs. 2-6, 2-7). D_2 shortening was directed east-west, and resulted in the development of a spaced axial planar cleavage (S_2), in places a crenulation of S_1 cleavage, and is associated with

upright west verging folds in some units, which vary in tightness from gentle to isoclinal (Plate 2-4a). S_2 is also a plane of flattening, defined by the shape of clasts in unit Mcgl on Silver Star Mountain.

Compositional layering (S_0), S_1, and S_2 surfaces were folded about an east-west axis (Figs. 2-5, 2-6, 2-7) during north-south oriented shortening (D_3). This deformation resulted in broad map scale folds that plunge east and verge north, with amplitudes >2 km and wavelengths > 9 km. Mesoscale open to isoclinal folds, with amplitudes between 5 and 30 cm, and wavelengths of cm to several m are heterogeneously distributed throughout all Mesozoic and older rock units in the area (Figs. 2-1, 2-8). Mesoscale folding appears most intense in areas near the axis of this fold, and orientations of penetrative fabrics show the greatest variability in this area (Fig. 2-1).

Similar deformation structures are visible within rocks throughout the field area. In suitable lithologies, layer parallel to near-parallel foliation (S_1) is consistently observed, and interpreted as resulting from D_1 deformation (Figs. 2-6, 2-7). On Vernon Hill, where three-dimensional exposures of outcrops are common, D_2 folding is also evident within Pmv, Pccs, and Pcs units, defined by bedding (S_0) and a near bedding-parallel cleavage (S_1) (Figs. 2-6, 2-7; Plates 2-1e, 2-4c). Unit Pccs is characterized by tight to isoclinal folds that are co-axial with D_2 structures (Plates 2-1e, 2-4c). D_2 resulted in spaced cleavage (S_2) development in these units, which is axial planar to mesoscale folds where observed. S_2 foliations were subsequently folded about a northeast trending fold axis in this area during D_3 (Fig. 2-5).

The 145 Ma Jgtd on Vernon Hill places constraints on the timing of latest deformation. The foliated nature of this intrusion indicates that D_3 deformation must be syn- or post-145 Ma. Foliation of rafts within the pluton are folded about a shallowly east plunging fold axis (91/8, Fig. 2-7), suggesting that plutonism post-dates D_3 folding, but occurs before the end of D_3 (Fig. 2-7).

The most recent folding episode is related to an episode of extension (D_4) in the Eocene that affected the entire southern Canadian Cordillera. There are various models proposed that describe the mechanisms and speculate on the causes of this extension (e.g. Brown and Read 1983; Templeman-Kluit and Parkinson 1986; Bardoux and Mareschal

1994; Johnson and Brown 1996) that will not be outlined here. Normal faulting associated with this extension resulted in localized outcrop scale drag folds.

Faulting

At least three episodes of faulting occurred within the mapped area. The earliest was a well-developed mylonite zone, at least 1.5 to 2 km thick, which occurs on Silver Star Mountain within units Dcq, Pba, and Pcs. In units Dcq and Pba, where rocks are coarse-grained, mylonitic fabric is most apparent in the granitic and pegmatitic sills and dykes intruding the rocks. In unit Pcs, where compositional layering is preserved, mylonitic foliation is apparent through preservation of rootless isoclines parallel to layering, indicating transposition of original bedding. In thin section, asymmetric shear sense indicators including c-s fabric, c' structures, and winged porphyroblasts (Plate 2-5) attest to the non-coaxial strain. Quartz grains show textures indicative of ductile deformation, including undulose extinction, ribbons, and serrated grain boundaries. Plagioclase, on the other hand, behaves variably in both ductile and brittle manners, suggesting formation of this zone between temperatures of 300°C and 450°C (Scholz 1988). Three oriented samples from layered rocks in this zone indicated the sense of shear to be consistently top to the east along these north-striking mylonitic shear planes (Plate 2-5). This mylonite zone extends to the eastern portion of the map area to unit Pba, outcropping along the west side of Trinity Valley, where it is best developed within intrusive granitic rocks of assumed Jurassic age. A stretching lineation associated with this zone is oriented east-west (Fig. 2-8). In unit Pcs, a biotite aggregate lineation parallels this stretching lineation (Fig. 2-8). One sample of foliated granite near Sovereign Lake, however, shows well-developed c-s fabric with a top to the west sense of shear, but attitude that is concordant with surrounding rocks (Plate 2-5g). A more detailed examination of this zone may determine is these data are related, and age determinations on this granite would place a maximum age on its deformation.

Constraints on the timing of mylonitic deformation are provided by cross-cutting relationships with granitoid rocks, including multiple phases of pegmatite. As recognized by Jones (1959), there are pre-, syn- and post-tectonic granites in the Silver Star area.

This mylonite zone post-dates peak metamorphism (see below), indicated by offset kyanite and staurolite grains by c' structures within the mylonite zone (Plate 2-5), an interpretation supported by fractured and broken up garnet grains within this zone, and pressure shadows surrounding garnets (Plate 2-5). Peak metamorphism was a static event that overprinted regional D_1 fabric, and this mylonite zone is folded during D_2 deformation, indicating that mylonitic deformation occurred between peak metamorphism and D_2 folding.

An east-west striking fault in the northern portion of the map area places unit Pba over PSC and Pcs rocks, and is inferred to be associated with the second phase of folding (D_3). This fault contact was not observed in the field. Evidence for this fault includes the truncation of unit PSCmb, and the steep orientation of the contact between units Pba and Pcs near Kendry Creek (Fig. 2-1), inferred from the surface trace across topography. This fault is interpreted to be a steep contraction fault, dipping between approximately 60 and 75°, with a minimum dip-slip displacement of 1 to 1.5 km (cross section A-A', Fig. 2-1).

Local evidence of shearing (99 JU 130, 134, 411, and 457, Appendix 2-1) near the contact of Pmv and Pccs with Pcs on Vernon Hill indicates that a fault contact between these units may be possible, although it is not inferred here due to the limited number of localities at which such deformation was observed. Deformation at 99 JU 130 was brittle, while 99 JU 134, 411, and 457 show semi-brittle to ductile deformation. In thin sections of the latter, quartz grains show undulose extinction and serrated grain boundaries. It is inferred that this deformation is related to localized Eocene extension, discussed below.

The most recent faults are related to regional extension in the Eocene, a phenomenon well documented throughout the Canadian Cordillera (e.g. Brown and Read 1983; Templeman-Kluit and Parkinson 1986; Bardoux and Mareschal 1994; Johnson and Brown 1996). Along the Coldstream Valley in the southern portion of the map area, four normal faults are inferred that post-date deposition and intrusion of units in Evvs, interpreted to be Eocene in age, and juxtapose younger rocks on older rocks in some areas (Fig. 2-1). These faults were not observed, but are inferred to dip steeply (> 60°) based on surface traces of these faults along topography. These faults are likely temporally associated with, and may have acted as conduits for, hydrothermal alteration, which is

enhanced along the two faults northeast of Lavington. Along the normal fault northeast of Becker Lake on Vernon Hill, rocks have been bleached and leached, and this alteration is noted as the Lavington Zone on BCGS MINFILE report no. 082LSW120. At the outcrop scale, normal faults with displacements of millimeters to meters, parallel to compositional layering or schistosity where observed, also document this extension (Plate 2-4d). These late faults can make the interpretation of structural data more difficult by rotating earlier fabrics.

Discussion of Cross-Sections

On cross-section constructions (Fig. 2-1), lines separating units represent enveloping surfaces, within which rocks are heterogeneously deformed, varying from homoclinal to isoclinal at the outcrop scale. These enveloping surfaces are intended to define the gross lithological layering throughout the area, and dip shallower than schistosity, and often bedding, measured at the outcrop scale.

Metamorphism

Metamorphic grade in the study area varies from partial melting (above second sillimanite isograd) in lower horizons of Pba, to chlorite-muscovite-grade in upper horizons of unit Ms, to epidote alteration in unit Evvs. A transition from sillimanite-K-feldspar-grade to chlorite-muscovite-grade occurs over a vertical thickness of approximately 1.5 km on Silver Star Mountain, a progression that should occur over a depth of approximately 12 to 15 km under normal geothermal gradient conditions. This transition appears to be progressive, with all intermediate metamorphic zones present, but attenuated. The reason for the attenuation is beyond the scope of this study, but may be related to stretching and flattening attested to in unit Pscgl, where quartzite cobbles show length:width:height ratios of between 5:2:1 and 10:2:1 (Plate 2-1d). However, the timing of this ductile deformation in Psc remains uncertain, and may be pre-Triassic (e.g. Erdmer et al. 2001).

At least three phases of metamorphism occurred within the mapped area. Metamorphism accompanied regional cleavage development (S_1/D_1), along surfaces parallel or near parallel to compositional layering. S_1 surfaces are defined by platy

mineral growth, including chlorite and muscovite in upper horizons, and biotite and amphibole in lower horizons, recording greenschist to amphibolite-grade conditions. These surfaces are overprinted by a random growth of metamorphic minerals (Plate 2-6). For example, in unit Ms, this event is indicated by the presence of randomly oriented biotite, muscovite, and chlorite. Unit Pcs has randomly oriented porphyroblasts of staurolite, kyanite, garnet, plagioclase, biotite, and muscovite (Plate 2-6a). Unit Pmv is characterized by randomly oriented biotite and/or amphibole. Sillimanite-bearing Pba is somewhat more difficult to interpret due to intense overprinting by subsequent shear fabrics. However, static porphyroblasts of the same mineral assemblages as in unit Pcs are present, including rare relic kyanite and staurolite that has a "moth-eaten" appearance (Plate 2-6b, c), suggesting they are not in equilibrium with the present assemblage.

Mylonite development on Silver Star Mountain was accompanied by sillimanite growth in unit Pba, roughly parallel to the stretching lineation. In unit Pcs, biotite-grade metamorphism is indicated by the presence of biotite aggregates parallel to the stretching lineation in the underlying Pba (Fig. 2-8). These aggregates are inferred to be prograde based on their well-defined crystal habit and the lack of any relic minerals preserved within them.

Metamorphic biotite, muscovite and chlorite define a steep spaced cleavage (S_2), with a spacing of 0.2 to 1 mm, that is associated with first phase folding (D_2).

Retrogradation of metamorphic minerals occurs in all metamorphosed rock units, indicated by partial reactions to amphibole, biotite, chlorite and sericite, and is likely related to an Eocene thermal event accompanied by volcanism in the area. These events are also likely responsible for epidote alteration of some Eocene units.

Geochronology

Methodology and Analytical Technique

U-Pb geochronology was applied to zircons from three samples, in attempt to determine the timing of crystallization of two granitic units (00 JU 01, 00 JU 02), and to examine the provenance of Mcgl (JU SS CGL, Plate 2-3a,b). All processing and analyses were completed at the University of Alberta. Following mechanical breakdown of

samples using a sledgehammer and rock press, heavy mineral separates were obtained using a jaw crusher, disk mill and Wilfley table. Further isolations were made using a 70-mesh sieve and Franz isodynamic magnetic separator, followed by density separation using methylene iodide. If zircon samples were large, further separation using the Franz separator was undertaken. Zircons were then hand picked and separated into fractions based on similarities of shape, size, colour and inclusions. No fractions were abraded prior to analysis. Following separation into fractions, zircons were processed in an ultra-clean laboratory to extract U and Pb, and then analyzed by thermal ionization mass spectrometry on a VG 354 mass spectrometer in the Radiogenic Isotope Facility. Mineral fractions and analytical results were processed according to procedures outlined in Heaman et al. (2002), and results are shown in Table 2-2. All analytical data were standardized against the NBS981 Pb and U500 U standards, with errors reported to 1σ. Age determination calculations were completed using the program Isoplot (Ludwig 1992) and denote discordia line upper and lower intercept ages based on two-error linear regression treatment of the data, with uncertainties reported to 2σ. The ages were calculated using the decay constants and present day $^{238}U/^{235}U$ ratio of Jaffey et al. (1971).

Sample Descriptions

Sample 00 JU 01 is a foliated granite from Vernon Hill (Fig. 2-1), considered representative of unit Jgtd, which varies from granite to granodiorite in composition. 00 JU 01 contains accessory amounts of biotite and garnet, and trace amounts of muscovite. The sample shows evidence of shearing, with strain apparent in quartz grains and in K-feldspar. Plagioclase grains are visibly zoned in thin section. Cross-cutting relationships between this pluton and foliation in surrounding host rocks place timing constraints on earliest deformation, but the internal fabric of this rock places a maximum age on the latest deformation.

Sample 00 JU 02 is a foliated muscovite-tonalite sill from near Sovereign Lake on Silver Star Mountain, where it cuts foliation in unit Pcs (Fig. 2-1). This sample contains accessory amounts of biotite and rutile. 00 JU 02 is considered part of the Silver Star Intrusions (see above) that are pervasive within Pba and Dcq, and become diminished in

quantity upward in the section through unit Pcs. This rock places a minimum age on unit Pcs, and may record pre-Triassic deformation within the area.

Sample JU SS CGL is a conglomerate sample of unit Mcgl (Ms) where it outcrops along the road to Silver Star Mountain (Fig. 2-1, Plate 2-3, Appendix 2-1). This unit is described under the Stratigraphy section, as part of unit Ms. Analyses on this sample aimed at testing for detrital contribution from sources of North American affinity, and to provide a possible maximum age for Mcgl.

Zircon Descriptions and Results

Three fractions of zircon were analyzed from sample 00 JU 01, chosen from the 1° magnetic fraction, separated during the final Franz procedure run at 1.8 A. These zircons had moderate to high U levels (366 to 643 ppm) and Th/U ratios (0.26-0.34; Table 2-2). Fraction 1 consisted of 48 clear, slender, euhedral zircons (Plate 2-7a) that gave a $^{207}Pb/^{206}Pb$ date of 156.3 ± 0.9 Ma and was the least discordant at 5.8%, (Table 2-2). Fraction 2 consisted of 9 of the larger euhedral or nearly euhedral grains, which contained mineral inclusions (Plate 2-7b). These zircons gave a $^{207}Pb/^{206}Pb$ date of 167.0 ± 1.7 Ma and were 10.9% discordant (Table 2-2). Fraction 3 was an exceptionally large euhedral grain (~5 mm in length, Plate 2-7c) with mineral inclusions, and yielded a $^{207}Pb/^{206}Pb$ date of 167.3 ± 2.5 Ma, and was 10.5% discordant (Table 2-2). Combined, these three fractions define a discordia line with a lower intercept of 145 ± 4 Ma, and an upper intercept of 587 ± 240 Ma (Fig 2-3).

Two fractions were run from sample 00 JU 02, chosen from the 1° magnetic fraction separated during the final Franz procedure run at 1.8 A. For this sample, the 1° magnetic fraction was considered the best. Fraction 1 consisted of 16 large, colourless, subhedral zircons that lacked any visibly apparent cores or inclusions, and was 20.8% discordant (Plate 2-8a; Table 2-2). This fraction had moderate U levels (389 ppm) and low Th/U ratios (0.14), which can be characteristic of metamorphic zircons (Table 2-2). Fraction 1 gave a $^{207}Pb/^{206}Pb$ date of 302.5 ± 1.4 Ma (Table 2-2). Fraction 2 was 66.0% discordant, had similar chemical characteristics to Fraction 1 (307 ppm U, Th/U = 0.13), and yielded a $^{207}Pb/^{206}Pb$ date of 765.2 ± 1.3 Ma (Table 2-2).

Little zircon was recovered from a > 20 kg sample of Mcgl (JU SS CGL), leaving the final Franz step, which further separates zircons isolated during methylene iodide density separations, unnecessary. Five single-grain analyses were completed on zircons retrieved from this sample (Plate 2-9). Discordance among the zircons ranged from –12.3 to 69.4 % (Table 2-2). U levels were low, varying between 126 and 198 ppm amongst all fractions. Th/U ratios were quite variable, between 0.05 and 0.23 (Table 2-2). $^{207}Pb/^{206}Pb$ dates from the fractions varied between 166.1 ± 27.7 and 771.9 ± 21.2 Ma (Table 2-2). Fractions 1, 2, 3, and 5 plot, within error, on the Concordia curve, between approximately 184 and 209 Ma (Fig. 2-4). Measurements from Fraction 3 are not used in any age calculations due to poor precision during analyses, and the high concentration of common Pb in the sample (114 pg, Table 2-2). Unusual for data from detrital zircon studies are that two combinations of three zircon analyses lie on a discordia line. Fractions 2, 4 and 5 define a discordia line with a lower intercept of 182.6 ± 4.2 Ma, and an upper intercept of 1646 ±110Ma, with an MSWD of 1.8 (Fig 2-4b). Fractions 1, 2, and 4 also define a discordia line with a lower intercept of 192 ± 3 Ma and an upper intercept of 1799 ± 110 Ma, with an MSWD of 1.9 (Fig. 2-4c).

Interpretations and Implications

The 145 ± 4 Ma lower intercept of the discordia line from sample 00 JU 01 (Fig 2-3), is interpreted to be the igneous crystallization age of unit Jgtd, with the upper intercept suggestive of inheritance from a possible Proterozoic source. However, the lack of precision of the upper intercept, 587 ± 240 Ma (Fig.2-3), makes speculation difficult. It is possible that the lower intercept represents a metamorphic age, but this seems unlikely based on the near concordant analyses, and the chemical characteristics of the zircons. A crystallization age at the Jurassic-Cretaceous boundary provides a minimum age for units Pmv and Pes and foliation surfaces cut by this pluton, and a maximum age of latest deformation. These results are indicative of magmatic activity in the Silver Star area during the late Jurassic - early Cretaceous time, which is interpreted as a period of magmatic quiescence in this region and the Cordillera in general (Woodsworth et al. 1991; Yorath 1991).

Possible interpretations of data from sample 00 JU 02 are offered with little confidence at this time. If these fractions lie on the same discordia curve, two interpretations are possible. The lower intercept of 237.5 ± 1.1 Ma may represent the age of the intrusion, with an inherited component from crust with an age of 2388 ± 49 Ma (Fig. 2-9). If the zircons are metamorphic, then the lower intercept may represent a metamorphic event, and the upper a possible crystallization age. However, that implies that units Pcs and Pba are older than 2388 Ma, which is impossible if the underlying unit Dcq is Devonian. It is possible that the highly discordant data is indicative of the complex geologic processes that occurred on Silver Star Mountain, including multiple episodes of deformation and metamorphism (see above).

The limited number of zircons retrieved from JU 88 CGL (Mcgl), and the unusual fact that fractions 3 and 4 can be fit onto a discordia line with either fraction 1 or 5, suggests two possibilities in which three zircon fractions were sourced from the same rock. Fraction 3 also falls on these lines, but is not considered because of high amounts of common Pb (114 pg) and poor precision during measurement of isotopic ratios (Table 2-2). Lower intercepts of these discordia lines are interpreted to represent possible crystallization ages of this source, between 182.6 ± 4.2 Ma (fractions 2, 4, and 5) and 192 ± 3 Ma (fractions 1, 2, and 4), and upper intercepts to represent inheritance from zircons with an average age between 1632 (fractions 2, 4, and 5) and 1799 ± 110 Ma (fractions 1, 2, and 4) (Fig. 2-4). This interpretation provides a maximum age of early Jurassic for unit Mcgl, making correlations with the Ymir and/or Rossland groups in the Kootenay Arc region, approximately 160 km to the east, or the early to middle Jurassic Ashcroft Formation, approximately 120 km to the west, possibilities. Of the two possible maximum age interpretations, 192 ± 3 Ma may be more likely, as sources of this age are abundant, and an upper intercept of 1800 Ma matches the 1800-2100 Ma ages of exposed basement rocks throughout this region (Armstrong et al.1991; McDonough and Parrish 1991; Murphy et al. 1991; Parkinson 1991). The penetrative deformation and presence of comparable fabric within these rocks to underlying rocks of inferred upper Triassic age suggests that they have undergone the same episodes of deformation and metamorphism, which further requires an early Jurassic age for these rocks if this basin was closed by

185-187 Ma (Murphy et al. 1995), and also suggests the maximum age interpretation of 192 ± 3 Ma is more likely. The age determinations were not available during mapping of these rocks, and future research should focus on determining the extent of rocks of this age in the area, and examining the possibility that they were deposited after initial deformation of underlying strata.

Possible sources of these zircons are abundant in the Kootenay Arc region (Fig. 2.2b), and include the Elise volcanics of the Rossland Group, estimated to be between 197.1 ± 0.5 Ma (U-Pb zircon, Höy and Dunne 1997) and early Toarcian (Frebold and Little 1962, <183.6 +1.6/-1.1 from Okulitch 1999), although in places they may be as young as 173.1 +6/-0.2 Ma (U-Pb zircon, Höy and Dunne 1997). Other potential sources in the Kootenay Arc region (Fig. 3-2b) that correspond to the lower intercept age of 182.6 ± 4.2 Ma include the Cooper Creek stock (180.6 +6.5/-7.1 Ma, U-Pb zircon) and Alwyn Creek porphyry (185 +24/-29 Ma, U-Pb zircon), (Murphy et al. 1995). Rossland Group rocks are interpreted to have formed in a continental arc setting, and zircons show evidence of inheritance from crust with an average age of 2.28 Ga (Höy and Dunne 1997). This is also the case for the Cooper Creek Stock (2105 +264/-281 Ma) and the Alwyn Creek porphyry (2220 ± 120 Ma; Murphy et al. 1995). Potential sources also exist to the west, in the area of Quesnel arc volcanism. These include the Wild Horse Batholith (196 ± 1 Ma, U-Pb zircon, Parrish and Monger 1992), Bromley Pluton (193 ± 1 Ma, U-Pb zircon, Parrish and Monger 1992), Pennask Batholith (194 ± 1 Ma, U-Pb zircon, Parrish and Monger 1992), and Nicola Batholith (190 ± 10 Ma, Rb-Sr, unpublished data of R.L. Armstrong in Ghosh 1995). Within the eastern volcanic facies of the Nicola Group, potential sources include the Copper Mountain intrusions (Voigt Stock, 194 ± 7 Ma, K-Ar biotite; Lost Horse Gulch, 195 ± 8 Ma, K-Ar biotite; Smelter Lake Stock, 197 ± 8, K-Ar biotite; Preto 1972). Of these possibilities, an eastern origin is favoured because zircons from the Kootenay Arc region show evidence of inheritance from Proterozoic sources, a characteristic also seen in the Megl detrital zircons. Although it remains possible that the lower intercept age for zircons from JU 88 CGL may be metamorphic, with an inherited detrital component, this is unlikely based on the

low metamorphic grade of the strata, and the fact that several zircons plot near the Concordia curve.

Isotope Geochemistry

Sampling Methodology

Seven samples were selected for Sm-Nd isotopic analysis (Table 2-3). Sample 98 JU 162 (Pcs) was originally mapped as part of unit Ms, and analyzed as part of the provenance study on Upper Triassic metasedimentary rocks presented in Chapter 3 (Unterschutz et al. 2002). The remaining six samples are of igneous rocks, analyzed to assist in interpretation of the tectonic setting of the Silver Star area. Sample 98 JU 532 (Maug) provides a test of whether this augite porphyry may be a flow within the Ms succession, through comparison with available data from Nicola Group volcanic units west of the study area. Samples 98 JU 606, 513, and 568 are from layers parallel to bedding in Ms strata. They were originally thought to be flows in the Ms succession, but, subsequent mapping in 1999 revealed a cross-cutting relationship with unit Ms, and they are thought to be Eocene in age (Esp). Nd isotope analyses of samples 00 JU 01 (Jgtd) and 02 (Silver Star Intrusions), granite and tonalite respectively, were completed with the intent of integrating the results with U-Pb zircon geochronology results from the same samples, in attempt to determine the tectonic setting at the time of their emplacement.

Analytical Technique

Sm-Nd isotopic analyses were conducted at the Radiogenic Isotope Facility at the University of Alberta using isotope dilution mass spectrometry (see Creaser et al. 1997 for methods). Results are presented in Table 2-3. Samples 98 JU 606, 513, 568, 532, and 162 were run on a VG 354 mass spectrometer, on which the $^{143}Nd/^{144}Nd$ value determined for the Shin Etsu Nd standard was 0.512097 ± 12 (1 SD, n = 40). Samples 00 JU 01, and 02 were run on a Sector 54 mass spectrometer, on which the $^{143}Nd/^{144}Nd$ value determined for the Shin Etsu Nd standard was 0.512106 ± 16 (1 SD, n = 12). These standard values are in agreement with previous determinations for the standard by Tanaka et al. (2000). Data were corrected to a $^{143}Nd/^{144}Nd$ value of 0.512107 for Shin Etsu, which is equivalent

to 0.511850 for the La Jolla standard (Tanaka et al., 2000). Chemical processing blanks were < 400 pg for Nd and Sm.

Results and Interpretations

The composition of clastic sedimentary rocks tends to reflect their source areas, and, as the Sm-Nd isotopic system has been shown to be relatively unaffected by erosion, transportation, deposition, and low-grade metamorphic processes (Taylor and McLennan 1985), it can be used to provide information on the source areas of clastic rocks (e.g. Goldstein et al. 1984; Creaser et al. 1997). Sample 98 JU 162 from unit Pcs yields an εNd_{300} value of –5.5 and a T_{DM} model age of 1.59 Ga, suggesting derivation from an evolved continental crustal source (Table 2-3). An age of 300 Ma was used in calculations; the age of the rock is limited by underlying units Pba and Dcq of Devonian age, and overlying Upper Triassic rocks. A 50 m.y. difference in age would only change the εNd value by half an epsilon unit. This evolved composition is consistent with a pericratonic affinity, and with compositions of more inboard Pennsylvanian to Triassic clastic deposits of the Cordilleran miogeocline (Boghossian et al. 1996; Garzione et al. 1997).

Eocene biotite porphyry units give εNd_{50} values of –5.6 and –3.6, while the plagioclase porphyry unit gives an εNd_{50} of +2.8 (Table 2-.3). For the purposes of calculations in this study, a 50 Ma age is used for these samples (Table 2-3). In a comprehensive geochemical study of Paleozoic to Early Tertiary igneous rocks, Ghosh (1995) interpreted Paleocene to Eocene igneous rocks with intermediate εNd_T values (–2.4 to –7.6) to be sourced largely from mantle melting, with variable input from crustal material. This is consistent with observations of entrained rocks within Eocene dykes on Vernon Hill (Plate 2-2e), and T_{DM} model ages between 0.85 and 1.49 Ga. The positive εNd_T value from the plagioclase porphyry unit probably reflects a mantle origin for the melt, with a lesser degree of input from crustal materials. Further geochemical analyses, including Sr-isotope analysis, in addition to a geochronological study on these samples, may reveal the reason for the difference in Nd isotope compositions between these rocks.

The sample of Maug, 98 JU 532, yields an εNd_{220} value of +4.1 (Table 2-3), which is slightly less positive than values from contemporaneous Nicola Group volcanic rocks to the west (εNd_T +5.0 to +7.9, Smith et al. 1995). The positive εNd value of Maug lends support to interpretation of Maug as a flow within the Ms succession, correlative with volcanic rocks in the Nicola Group.

Jgtd (00 JU 01) from Vernon Hill yields an εNd_{145} value of –2.2, and a T_{DM} model age of 1.03 Ga (Fig. 2-1; Table 2-3). The negative value implies some interaction with continental crust, which is consistent with Proterozoic inheritance shown by zircons from this same sample. This value also is consistent with εNd_T values of +8 to -13 from intrusive Middle Jurassic through Cretaceous igneous rocks presented by Ghosh (1995).

The muscovite tonalite sample (00 JU 02) from the Sovereign Lake area on Silver Star Mountain yields an εNd_{300} value of –13.6, and a T_{DM} model age of 2.34 Ga (Table 2-3). The result is less precise than for other samples due to low concentrations of Sm and Nd (0.13 and 0.62 ppm, respectively), but a difference of 0.000020 in the measured $^{143}Nd/^{144}Nd$ ratio (the 2 SD uncertainty on this measurement) would only change the εNd_{300} value by 0.4 of an epsilon unit. This change would not alter the highly evolved character of this sample that could only originate from melting of continental crust. This suggests an *in-situ* melting origin for the Silver Star Intrusions in units Pba and Dcq. For the purposes of calculation, an age of 300 Ma was used, derived from the $^{207}Pb/^{206}Pb$ date from zircon fraction 1, the least discordant for this sample.

Discussion

Geologic History

The oldest rocks of known age in the study area, Dcq and Pba, represent a transition from shallow water, continental margin, dominantly quartzofeldspathic deposits in Devonian time, to deeper water, carbonaceous deposits of Pcs in the late Paleozoic. Lithologic similarities with the Silver Creek Formation (Pba) have led previous authors to variably correlate Pba and Dcq with North American rocks including the Paleozoic Lardeau Group and the Neoproterozoic Windermere Supergroup and Hunters Range Assemblage (Okulitch 1979; Johnson 1990, 1994; Thompson and Daughtry 1996).

Consistent with derivation from a continental source, but distinct from contemporaneous deposits of the Cordilleran miogeocline (εNd_T between –14.6 and –6.6, Boghossian et al. 1996; Garzione et al. 1997), are the εNd_{400} values for the Silver Creek Formation, between –20.2 and –22.2 (Erdmer et al. 2001). The abundant presence of mafic material (Pgr and equivalents?) intruding and possibly interlayered within unit Pba, may be indicative of a period of extension in or after Devonian time, and possibly rifting along the margin, similar to a 370 Ma episode of rifting in the northern Cordillera (e.g. Thompson et al. 1987). The presence of pyritic stringers, black slate, and abundant carbon in unit Pcs suggests deposition in a restricted basin environment. This basin may be part of a distal passive margin environment, or could be part of a back-arc basin environment, located between the more outboard late Paleozoic volcanic arc of the Harper Ranch Group and ancestral North America.

Unit Pcs is unconformably overlain by the Spa Creek Assemblage (PSC) in the northern portion of the map area (Fig. 2-1), indicating a transition from quiet basin sedimentation to that of an active volcanic regime. This may reflect migration of a late Paleozoic arc craton-ward into back-arc basin sedimentary rocks, or signify the end of passive margin deposition. The presence of the quartzite cobble conglomerate (PSCcgl) at the base of this succession suggests derivation from a nearby source of continental affinity. This is consistent with correlative conglomerate units of the Spa Creek Assemblage west of the study area, in which clasts of quartzite, schist, and Eocambrian granite are found (Erdmer et al. 2001). Potential sources may have been uplifted during tectonic processes associated with volcanism in the area. The timing of deposition of PSC remains to be established, but an Upper Paleozoic age is inferred. Unit Pmv, which overlies Pcs in the southern portion of the map area, may represent a more distal equivalent to PSC, and unit Pccs eroded components from PSCmb. The contact between Pcs and Pmv was not observed, leaving the nature of it uncertain, but the concordance of structures and metamorphic grade across this contact, and within both units, suggests that it may be conformable. Late Paleozoic volcanism is also indicated by the presence of unit PHRmv, which is interlayered and overlain by unit PHRmb, suggesting that the newly formed volcanic edifice may have provided a suitable environment for reef growth.

Provenance studies of the Harper Ranch Group (Quesnel subterrane) that span the U.S. - Canada border in the southern Kootenay Arc region (Fig. 2-2b) suggest that sediment was derived from source areas ranging in age from 0.37 to 2.7 Ga, which may have been proximal as suggested by the presence of quartzite clasts in conglomerate of the Upper Paleozoic Mount Roberts Formation (Roback and Walker 1995).

The contact between Late Triassic – early Jurassic rocks (Ms) and older units within the study area could be interpreted as either structural or unconformable, but based on the fact that unit Ms overlies every older unit in the area except Pgn, Pmv and Pccs, and that this basal surface cuts down through stratigraphy to the north, south and east of Silver Star Mountain, an unconformable basal contact is inferred. The mylonite zone in rocks underlying unit Ms on Silver Star Mountain and to the east along the Trinity Valley may represent a tectonic contact, however, mylonite is not observed elsewhere beneath rocks of the Quesnel "terrane", further suggesting that a tectonic contact is not the case. A sub-Triassic unconformity has been previously suggested for the Silver Star area (Jones 1959; Read and Okulitch 1977) and is documented in other areas of southeast British Columbia (Read and Okulitch 1977; Klepacki 1983; Klepacki and Wheeler 1985; Roback and Walker 1995).

An unconformable contact between unit Ms and older rocks in the area would imply a shift from a volcanic environment in the late Paleozoic, to one of a more distal, back-arc basin between the Quesnel volcanic arc to the west, and ancestral North America to the east, by the Upper Triassic. The presence of up to 40% carbon dust in Upper Triassic metasedimentary rocks implies a restricted basin environment. In this scenario, both North America and the Quesnel volcanic arc would have been potential sources for detritus in the interlayered sands, silts and muds of unit Ms. This possibility is supported by geochemical and isotopic characteristics of sediments spanning this proposed back-arc basin that are interlayered with volcanic units to the west and unconformable with North American derived sediments to the east, and which indicate a mixed provenance between rocks of a primitive arc nature, and evolved continental crust (Unterschutz et al. 2002). Maug may represent a period of enhanced volcanic activity, or migration of the volcanic arc eastward. An eastward migration of the arc is attested to by the occurrence of early

Jurassic volcanic rocks of the Rossland Group in the Kootenay Arc region, 250 km east of volcanic rocks of the Late Triassic Quesnel arc. Deposition continued into the early Jurassic, when schistose rocks of continental affinity and early Jurassic igneous rocks were exposed, eroded, and deposited in this basin (Mcgl).

The basin between the Quesnel "terrane" and North America is estimated to have closed by the late Early Jurassic (185-187 Ma, Murphy at al. 1995), suggesting initial deformation of these rocks prior to this time. Rocks were buried and a bedding parallel cleavage developed under greenschist to lower amphibolite metamorphic conditions. Lowermost units were buried to depths greater than 20 km, if normal geothermal gradient conditions are assumed, creating conditions under which peak metamorphic mineral assemblages formed, statically overprinting earlier foliation. Continued deformation led to mylonitization of units Dcq, Pba, and Pcs near Silver Star Mountain, in a top-to-the-east direction, under sillimanite-grade metamorphic conditions. Continued east-west shortening led to the development of map- and outcrop-scale west-verging folds, under greenschist to lower amphibolite grade metamorphic conditions. These structures were subsequently folded during north-south shortening that created broad, south-verging, map-scale folds. Unit Jgtd intruded and crystallized around 145 Ma, possibly after north-south shortening began, but prior to the end of deformation.

Extension and volcanism during the Eocene are attested to by the presence of breccia and conglomerate graben fill along the Coldstream Valley, porphyry dykes (Esp) cutting older rock units in the area, volcanic rocks (Evvs), and normal faulting. Eocene units are capped by Miocene basalts (Mab) near Lavington that are the most recent evidence of volcanic activity in the study area. Mab is interpreted to have erupted in a back-arc setting, related to subduction of the Farallon plate (now Juan de Fuca plate) beneath the North American plate (Souther 1991).

North American Ties

The Quesnel "terrane" has been interpreted as an intra-oceanic arc that developed off the coast of North America, over an east-dipping subduction zone, and in places on top of Ordovician to early Triassic basement of oceanic and island arc affinity (Mortimer

1987). This is supported by geochemical and Nd isotope studies on Nicola Group volcanic rocks from this arc (Mortimer 1987; Smith et al. 1995). Paleomagnetic and biostratigraphic data from rocks of the Quesnel "terrane" have been used to suggest great distances separated this arc from the margin at this latitude as late as in mid-Cretaceous time (e.g. Carter et al. 1991; Taylor et al. 1984; Symons 1983; Irving et al. 1985; Rees et al. 1985; Symons 1985). Some of these studies suggest northward translation of up to 2400 km occurred between Cretaceous and Paleogene time. However, it should be noted that while these data can be used to suggest a more southerly origin, the paleontologic data do not require it, and the paleomagnetic data within the Quesnel "terrane" are sparse and highly variable. Most germane to this argument is that no such fault has been found in the southern Canadian Cordillera (Gabrielse 1991; Wheeler and McFeely 1991). Also in conflict with a southerly origin are geologic relationships in the Kootenay Arc region, where Upper Triassic rocks of the Quesnel "terrane" unconformably overlie rocks tied to, or derived from, North America (Klepacki 1983; Klepacki and Wheeler 1985), and where later shortening within these rocks occurred in the early Jurassic (Murphy et al. 1995). These interpretations also contradict geochemical evidence from the 200 Ma Lexington pluton in the same area, which intrudes strata of the Quesnel "terrane" and shows evidence of inheritance from Proterozoic basement (Dostal et al. 2001).

Early Jurassic detrital zircons from unit Ms of the Quesnel "terrane" in the Silver Star area show evidence of inheritance from Proterozoic crust, and are similar in age and inheritance to zircons from igneous rocks in the Kootenay Arc region, suggesting a depositional link between the two areas. Detailed studies within the Silver Star area show rocks of the Quesnel "terrane" to overlie all older rock units in the field area, except Pgn, Pmv and Pccs, which is consistent with a structural or unconformable basal contact. A mylonite zone was located beneath this contact on Silver Star Mountain and to the east in the Trinity Valley, but was not observed elsewhere in the field area. This suggests that Quesnel "terrane" strata in the Silver Star area may also sit unconformably on top of North American derived rocks. Geologic relationships describing unconformable contacts between the Quesnel "terrane" and rocks of North American origin, provenance studies on sediments within this "terrane" showing derivation from nearby old continental

crust, and igneous rocks intruding this "terrane" with Proterozoic inheritance prior to the proposed obduction onto the North American margin, can be interpreted to suggest that the Quesnel "terrane" developed as a distal continental margin arc, overlapping North American strata in the east, and arc and oceanic rocks in the west.

Table 2-1: Outcrop locations and descriptions of conglomerate units possibly correlating with Mcgl

Sample	Latitude	Longitude	Description
98 JU 605	50 18 39.2	118 59 57.6	clasts vary from several cm to >20 cm diameter; in general, smaller clasts are metasandstone, larger clasts are argillite; matrix varies from silt to sand sized particles; folded
99 JU 480	50 17 14.4	119 10 30.4	silty-sand matrix; clasts are mm to cm in diameter, angular, and flattened
99 LH 20	50 19 21.8	118 58 25.4	silty matrix; matrix-supported, with sub-rounded metasandstone clasts
99 LH 26	50 19 57.1	118 58 54.5	clast-supported; slate and metasandstone clasts, few mm to 15 cm in length; slate clasts contain sand clasts
99 LH 50	50 20 26.8	118 57 53.3	matrix-supported; interlayerd with metasandstone units; clasts include metasiltstone, metasandstone, slate and argillite; most clasts < 5cm in diameter

Table 2-2: U-Pb zircon results for samples from Silver Star area, southeastern British Columbia

Description*	Weight (μg)	U (ppm)	Th (ppm)	Pb (ppm)	Th/U	TCPb (pg)	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Model Ages (Ma) $^{206}Pb/^{238}U$	Model Ages (Ma) $^{207}Pb/^{235}U$	Model Ages (Ma) $^{207}Pb/^{206}Pb$	%Disc
JUSSCGL														
1 z, (1) yel, br	5	195	30	6	0.15	5	344	0.03017±6	0.2057±252	0.04943±59	191.6±0.3	189.9±2.1	168.4±27.4	-14.0
2 z, (1) sub, sor, br	5	126	29	5	0.23	7	180	0.03057±9	0.2191±457	0.05197±10	194.1±0.6	201.1±3.8	284.0±45.3	32.1
3 z, (1) sr, br, os	5	136	13	27	0.09	114	31	0.03186±9	0.2735±2930	0.06226±69	202.4±5.9	238.1±23.1	607.4±100.	71.5
4 z, (1) cl, ang, bd	4	156	8	7	0.05	8	209	0.03909±9	0.3501±362	0.06496±65	247.2±0.5	304.8±2.7	772.9±21.1	69.3
5 z, (1) cl, bd, os, fe	4	198	43	6	0.22	3	411	0.02896±5	0.2021±289	0.05063±70	184.0±0.3	186.9±2.4	224.1±31.6	18.1
00JU-01														
1 z, (48) sl, eu, cl, sm	167	643	190	15	0.30	11	14371	0.02311±6	0.1567±39	0.04918±2	147.3±0.4	147.8±0.3	156.3±0.9	5.8
2 z, (9) lg, min incl, eu to ceu, sp	172	663	171	15	0.26	63	2672	0.02339±1	0.1593±78	0.04940±4	149.1±0.7	150.1±0.7	167.0±1.7	10.9
3 z, (1) lg, min incl, br, eu	69	367	123	9	0.34	20	1844	0.02348±3	0.1599±27	0.04939±5	149.6±0.2	151.6±0.2	166.2±2.5	10.1
00JU-02														
1 z, (16) lg, sub	71	392	48	14	0.12	17	3854	0.03793±5	0.2739±42	0.05237±3	240.0±0.3	245.8±0.3	301.6±1.4	20.8
2 z, (96) sm, eu, most nc, some f	76	307	38	14	0.13	26	2388	0.04279±7	0.3818±68	0.06472±4	270.1±0.4	328.4±0.5	765.2±1.3	66.0

Notes: *(number of zircons in fraction), sl=slender, eu=euhedral, cl=clear, spg=some partial grains, ceu=close to euhedral, br=broken, lg=large, sub=subhedral, sm=small, nc=colorless, fi=fluid inclusions, bd=black dust, sr=sub-rounded, br=brown, os= orange stains, yel=yellow, so=slightly orange, ang=angular, pg=partial grain, fe=fractured edges; see Plate U-Pb for photos. All errors reported to 1 sigma. TCPb = total common lead in the analysis. Th concentration is estimated from the amount of ^{208}Pb and $^{207}Pb/^{206}Pb$ age, with correction for Pb-loss in discordant fractions. All atomic ratios were corrected for fractionation and initial common Pb (Stacey and Kramers 1975).

Table 2-3. Sm-Nd results for samples from the Silver Star area, British Columbia

Sample	Rock Type	Age (Ma)	Latitude (N)	Longitude	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$*	εNd_0	εNd_T	T_{DM} (Ga)
98JU-162	C-rich metasiltstone	300	50 32 34.0	119 25 15.5	4.05	19.98	0.1225	0.51221 ± 11	-8.4	-5.5	1.59
98JU-532	Augite porhphyry	220	50 21 40.2	119 04 50.7	2.97	13.31	0.1351	0.512760 ± 7	2.4	4.1	0.78
98JU-606	Biotite porphyry	50	50 19 17.5	119 00 49.8	7.79	36.99	0.1274	0.512431 ± 7	-4.0	-3.6	1.29
98JU-513	Biotite porphyry	50	50 22 15.0	119 03 38.2	5.54	26.12	0.1282	0.512327 ± 6	-6.1	-5.6	1.49
98JU-568	Plagioclase porphyry	50	50 21 40.5	119 04 33.8	4.29	18.27	0.1420	0.512762 ± 7	2.4	2.8	0.85
00-JU-01	Granite	145	50 15 07.4	119 12 34.5	4.72	26.91	0.1060	0.512438 ± 7	-3.9	-2.2	1.03
00-JU-02	Muscovite tonalite	300	50 21 26.3	119 06 26.8	0.13	0.62	0.1255	0.511803 ± 20	-16.3	-13.6	2.34

Notes: Upper Triassic sedimentary strata, from the Silver Star area and located on Figure 2-1, are detailed in Chapter 3. * ± 2 SD.

$\varepsilon Nd = [(^{143}Nd/^{144}Nd)_{Sample}(^{143}Nd/^{144}Nd_{CHUR})-1]*10^4$ (DePaolo and Wasserburg, 1976), values used were $^{143}Nd/^{144}Nd_{CHUR,today} = 0.512638$ (Goldstein 1984) and $^{147}Sm/^{144}Nd_{CHUR,today} = 0.1966$ (Jacobson and Wasserburg 1980). T_{DM} based on model of Goldstein (1984)

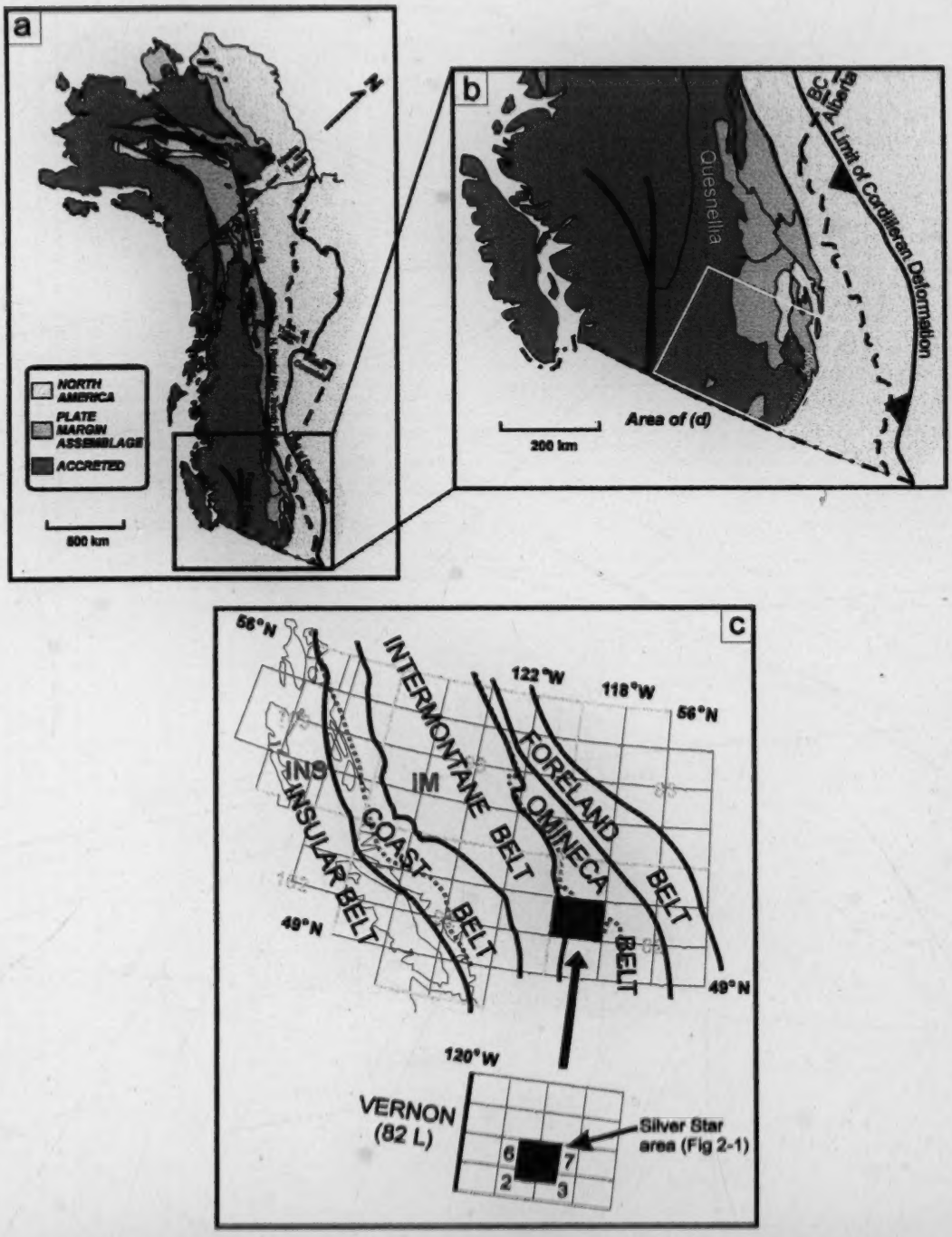
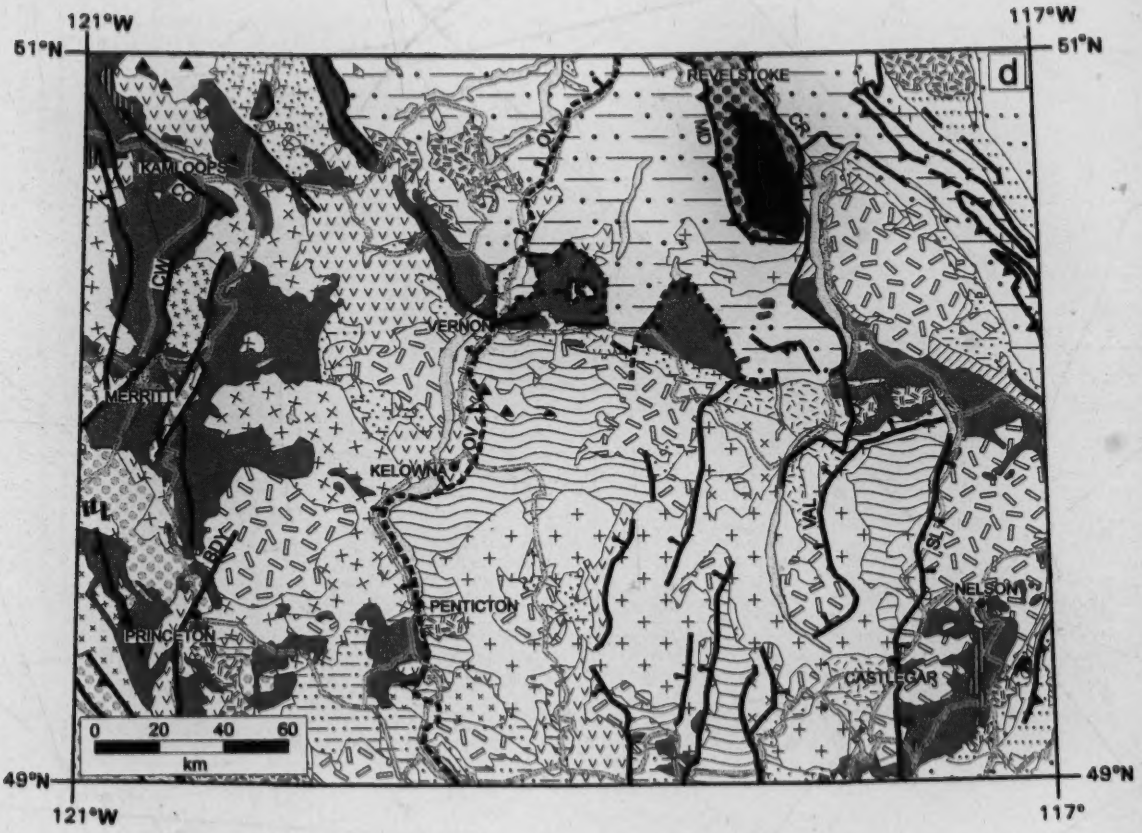


Figure 2-2: Regional geology of British Columbia. Maps showing (a) Canadian and Alaskan Cordillera, differentiating rocks presently interpreted to be of North American, plate margin assemblage, and accreted origin; (b) outline of Quesnel terrane, location of the Kootenay Arc, and outline of area in figure d; (c) geomorphological belts in black, superterrane boundaries in dotted grey: Intermontane (IM), Insular (INS), Vernon map area (82L), and the Silver Star area (Fig. 2-1), modified after Gabrielse et al 1991; (d) simplified tectonic assemblage assemblage map. Faults denoted are Cherry Creek (CC),Coldwater (CW),Boundary (BDY), Eagle River-Okanagan Valley (OV), Monashee Decollement (MD), Columbia River (CR), Valkyr (VAL),and Slocan Lake (SL). a, b and c simplified from Wheeler and McFeely (1991).



Igneous Units

- Early Tertiary plutonic
- Neogene back-arc volcanics
- Kamloops Group volcanics
- Late Cretaceous plutonic
- Mid-Cretaceous plutonic
- Late Jurassic - Early Cretaceous
- Middle Jurassic plutonic rocks
- Early Jurassic plutonic rocks
- Late Triassic plutonic rocks
- Devonian plutonic (Dg)
- Granodiorite, quartz diorite, and quartz monzonite, unknown age

Quesnel "terrane"

- Jurassic metasedimentary rocks
- Nicola, Slocan, Ymir, Rossland groups
- Harper Ranch Group
- Okanagan subterrane
- Jurassic - mid-Cretaceous easterly derived sediments, with some volcanics

Pericratonic rocks (tied to North America)

- Slide Mountain terrane
- Milford Group (Kootenay Terrane)
- Clastics and volcanics of Kootenay terrane

North American margin rocks

- Rocky Mountains - pasive margin
- Gog Group
- Upper Proterozoic Windermere Group

Shuswap Complex

- Undivided metamorphic rocks

Monashee Complex

- Paleoproterozoic - Paleozoic(?) cover sequence
- Paleoproterozoic basement gneiss
- Roads and highways
- Lakes
- Faults: normal, reverse, unknown, questionable

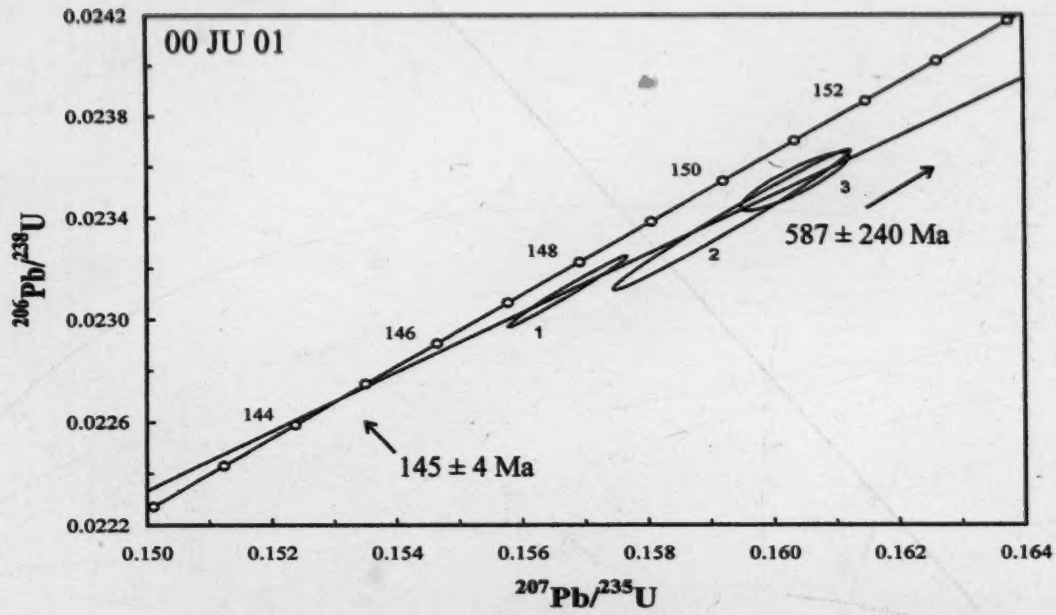
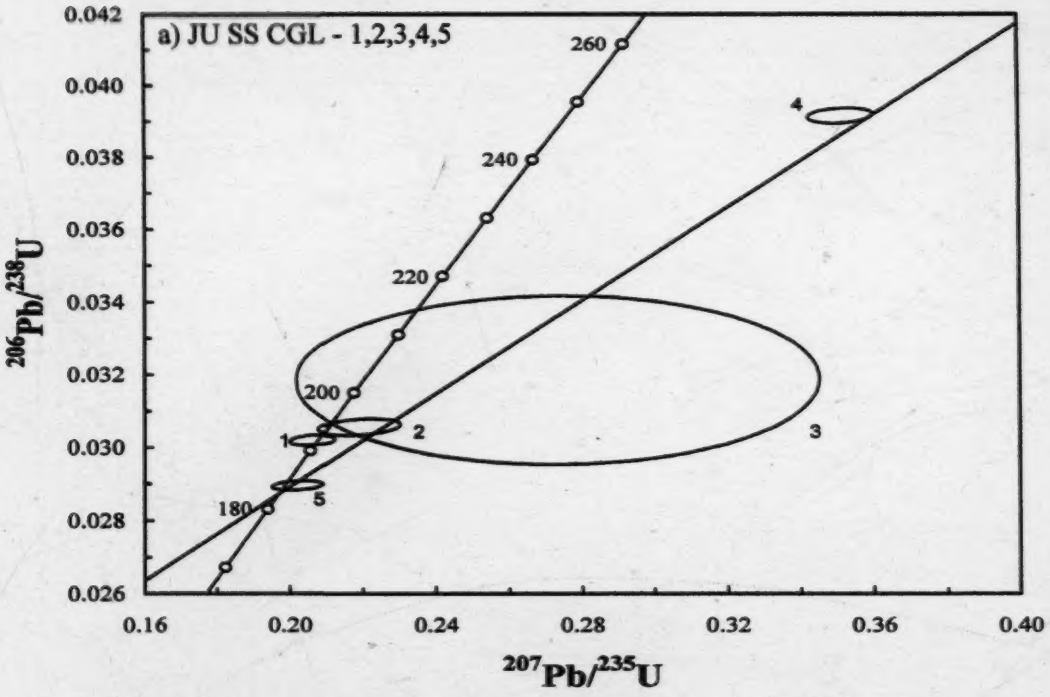
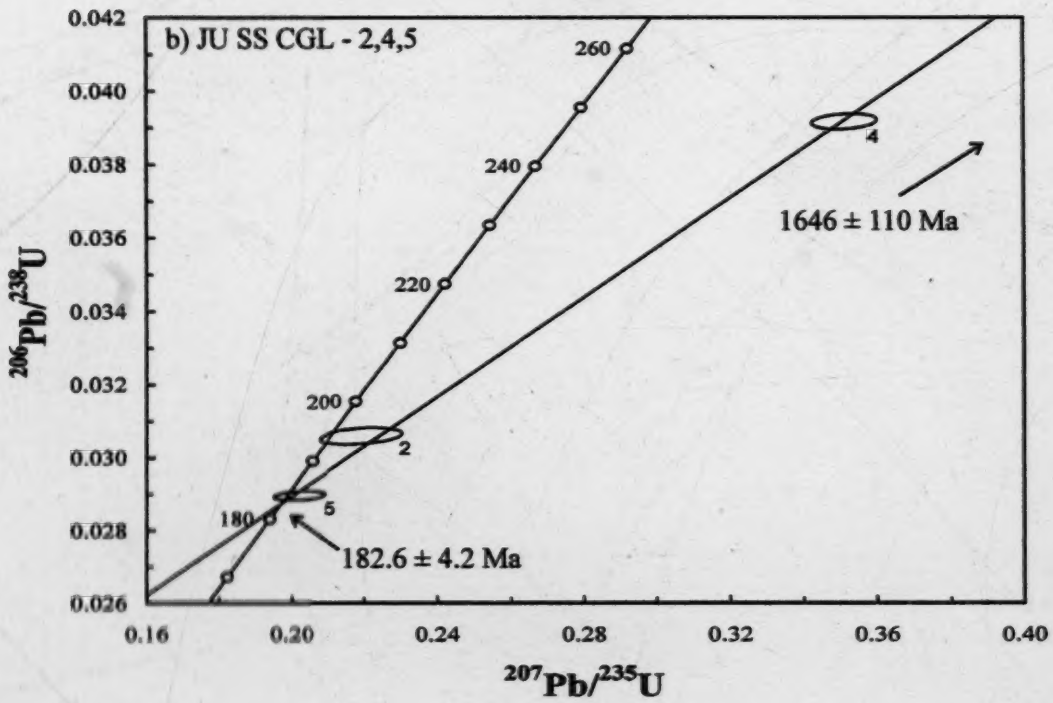


Figure 2-3: U-Pb concordia plot of zircons from 00 JU 01, the Vernon Hill granite. Error ellipses represent 2σ uncertainty. MSWD is 0.89.


a) JU SS CGL - 1,2,3,4,5
0.042
0.040
0.038
0.036
0.034
0.032
0.030
0.028
0.026
260
240
220
200
180
1
2
3
4
5
0.16
0.20
0.24
0.28
0.32
0.36
0.40
$^{206}Pb/^{238}U$
$^{207}Pb/^{235}U$


b) JU SS CGL - 2,4,5
0.042
0.040
0.038
0.036
0.034
0.032
0.030
0.028
0.026
260
240
220
200
180
2
4
5
1646 ± 110 Ma
182.6 ± 4.2 Ma
0.16
0.20
0.24
0.28
0.32
0.36
0.40
$^{206}Pb/^{238}U$
$^{207}Pb/^{235}U$

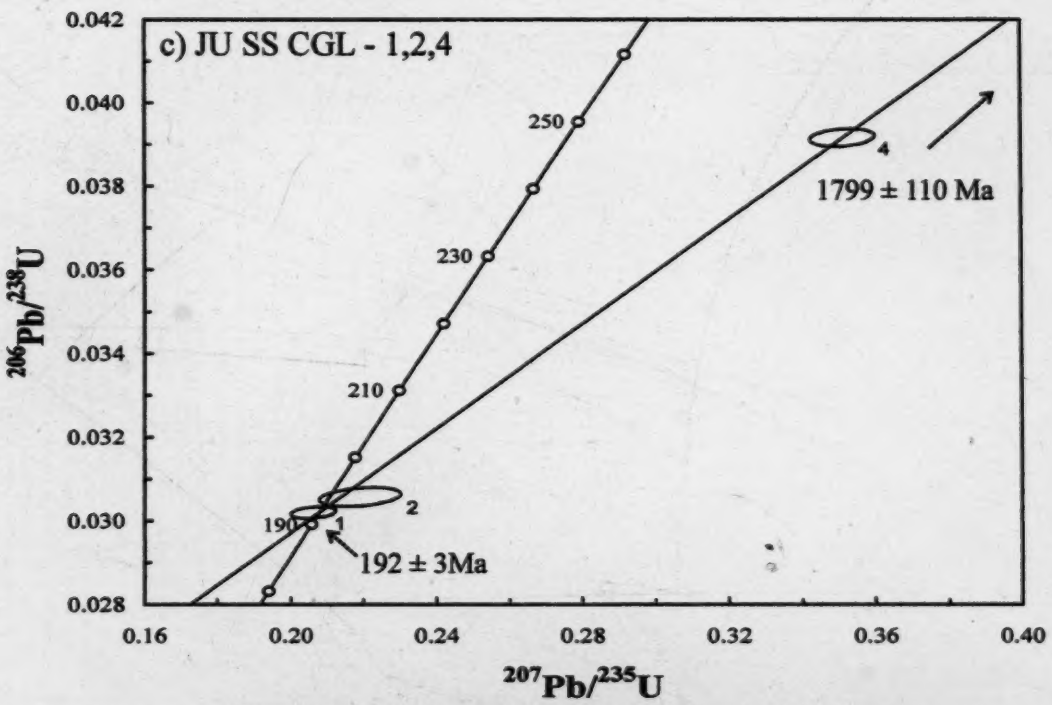


Figure 2-4: U-Pb concordia plots of zircons from JU SS CGL, conglomerate unit Mcgl (see Fig. 2-1). Plots show (a) all fractions, MSWD = 6.0 (b) fractions 2, 4, and 5, MSWD = 1.8, and (c)1, 2, and 4, MSWD = 1.9. Error ellipses represent 2σ uncertainty.

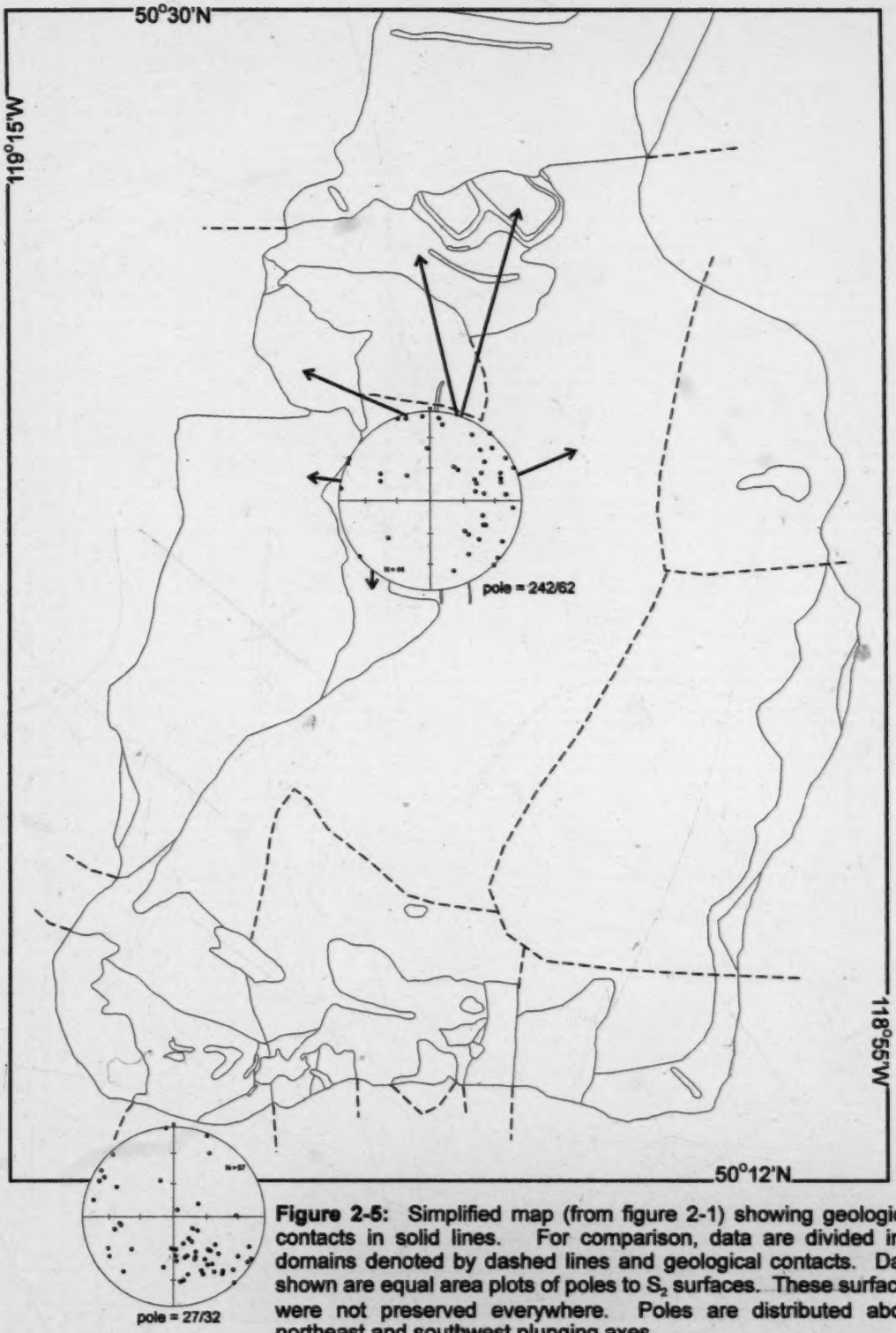


Figure 2-5: Simplified map (from figure 2-1) showing geological contacts in solid lines. For comparison, data are divided into domains denoted by dashed lines and geological contacts. Data shown are equal area plots of poles to S_2 surfaces. These surfaces were not preserved everywhere. Poles are distributed about northeast and southwest plunging axes.

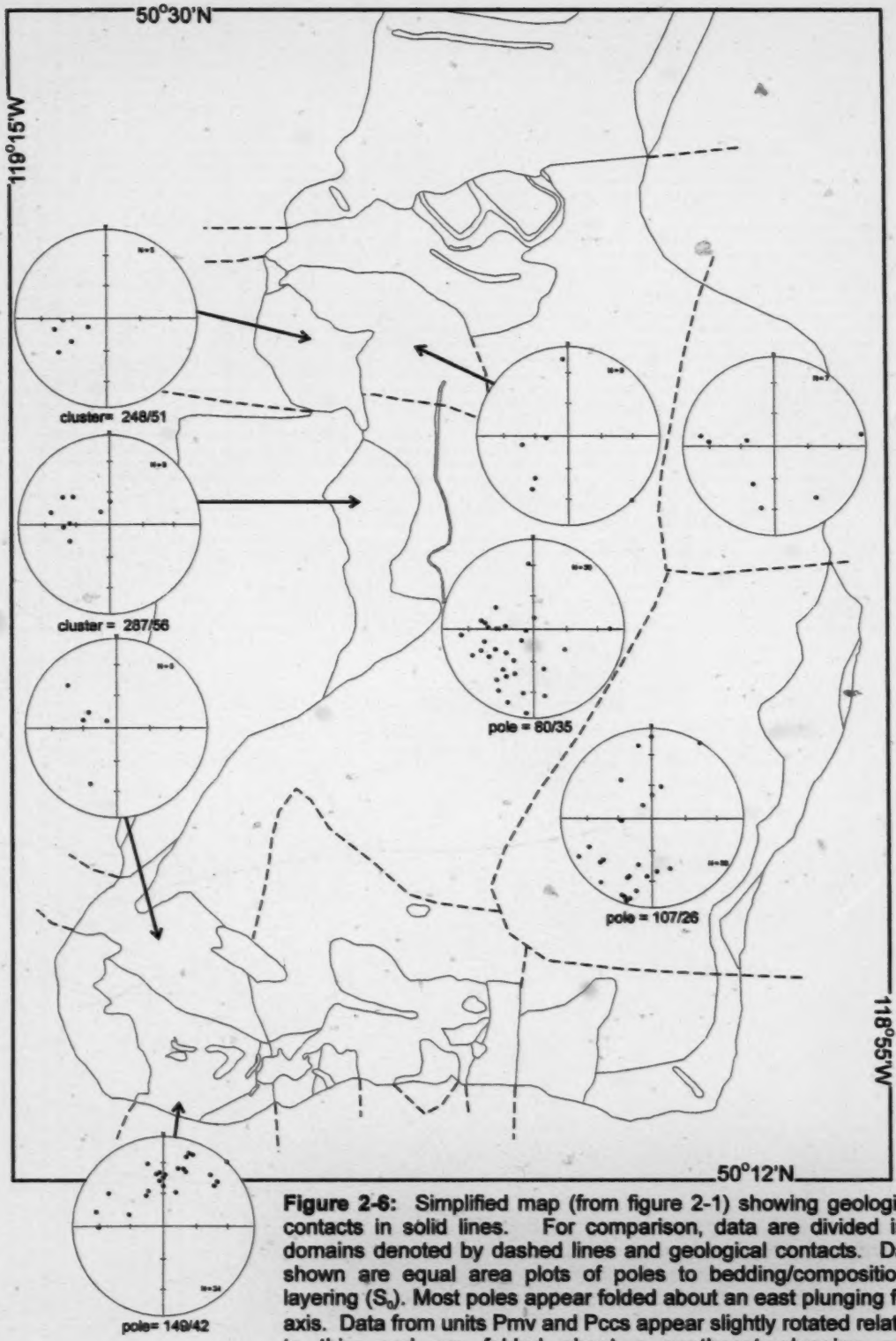


Figure 2-6: Simplified map (from figure 2-1) showing geological contacts in solid lines. For comparison, data are divided into domains denoted by dashed lines and geological contacts. Data shown are equal area plots of poles to bedding/compositional layering (S_0). Most poles appear folded about an east plunging fold axis. Data from units Pmv and Pccs appear slightly rotated relative to this, and are folded about a southeast plunging axis.

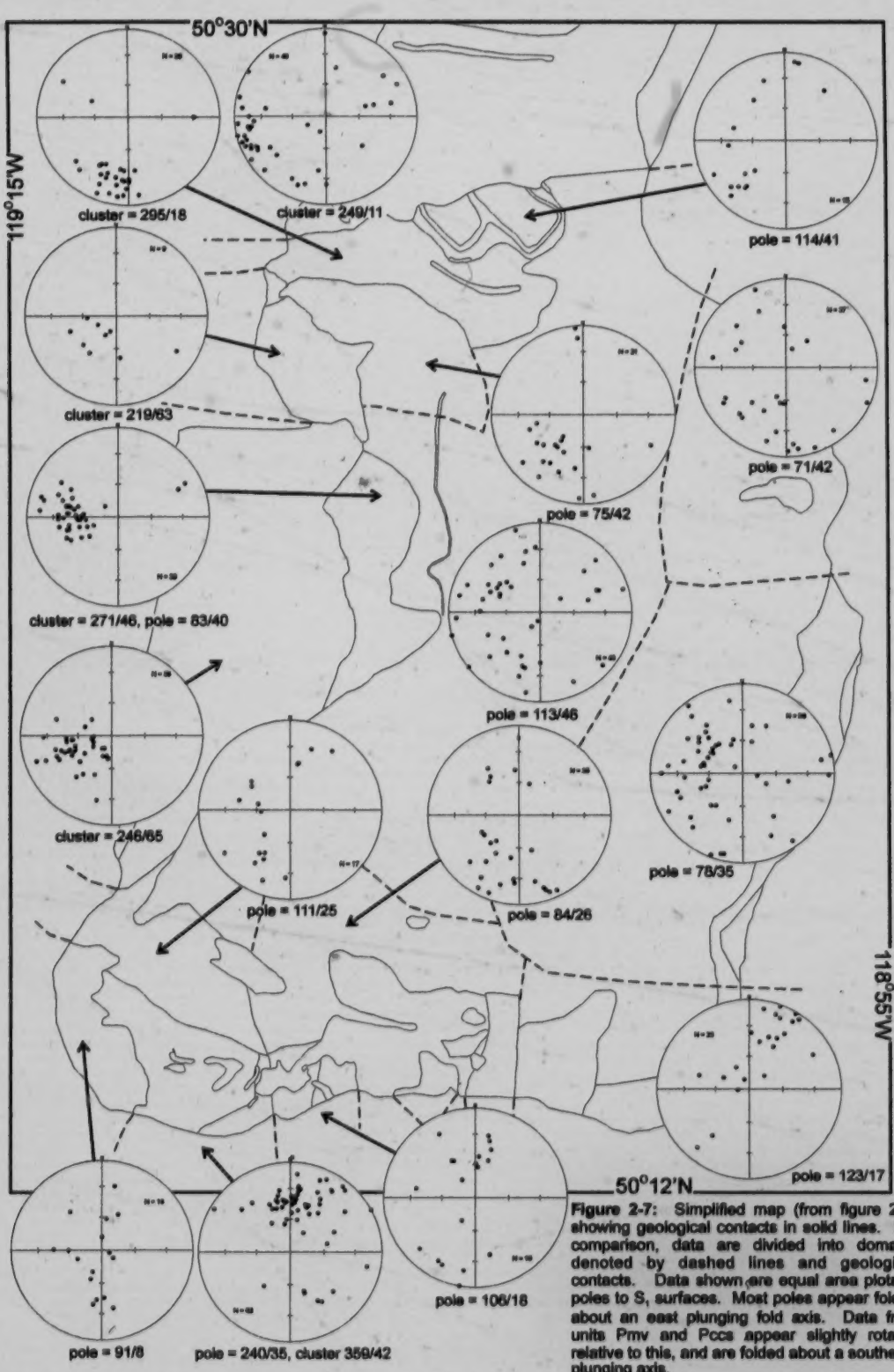


Figure 2-7: Simplified map (from figure 2-1) showing geological contacts in solid lines. For comparison, data are divided into domains denoted by dashed lines and geological contacts. Data shown are equal area plots of poles to S_1 surfaces. Most poles appear folded about an east plunging fold axis. Data from units Pmv and Pccs appear slightly rotated relative to this, and are folded about a southeast plunging axis.

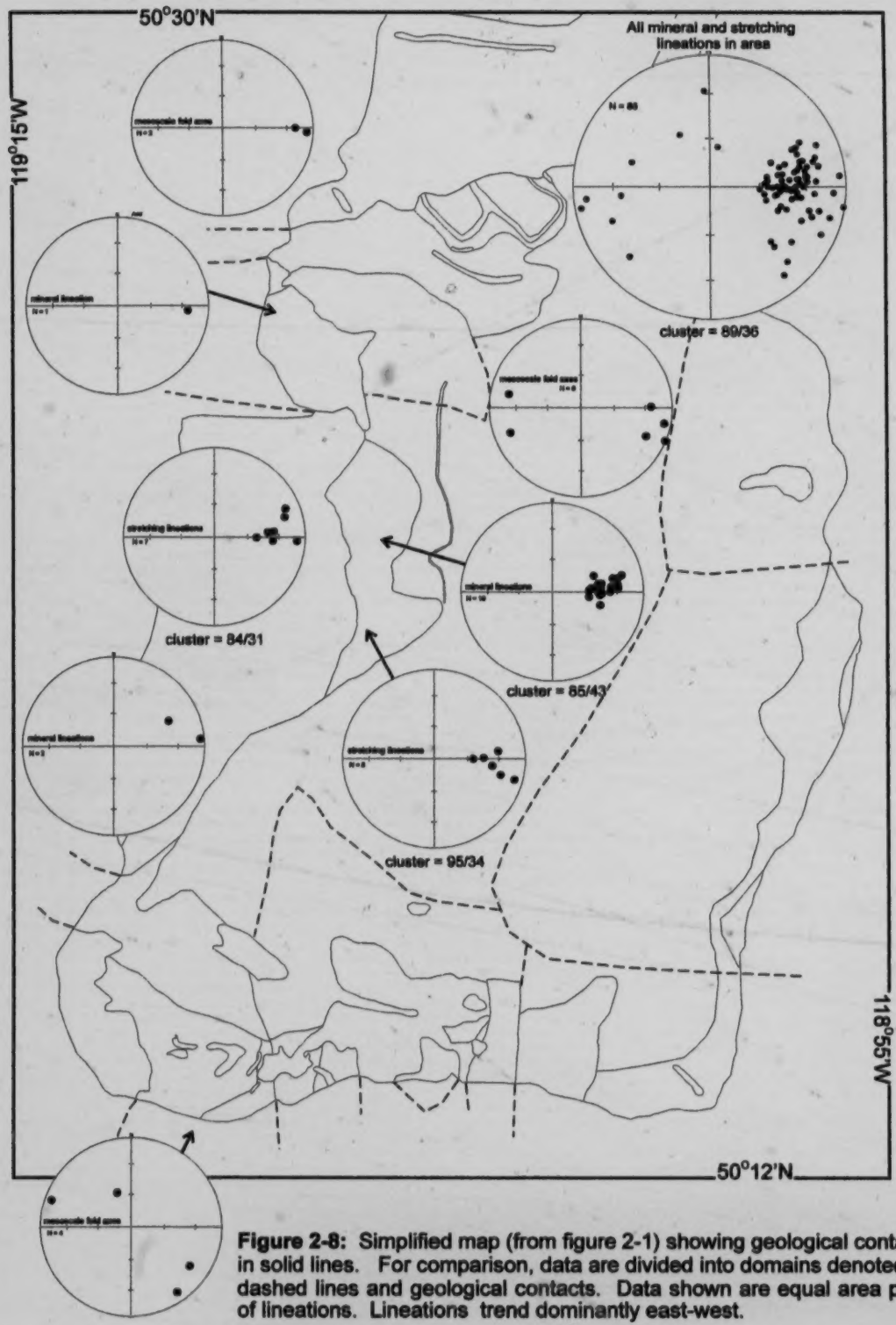


Figure 2-8: Simplified map (from figure 2-1) showing geological contacts in solid lines. For comparison, data are divided into domains denoted by dashed lines and geological contacts. Data shown are equal area plots of lineations. Lineations trend dominantly east-west.

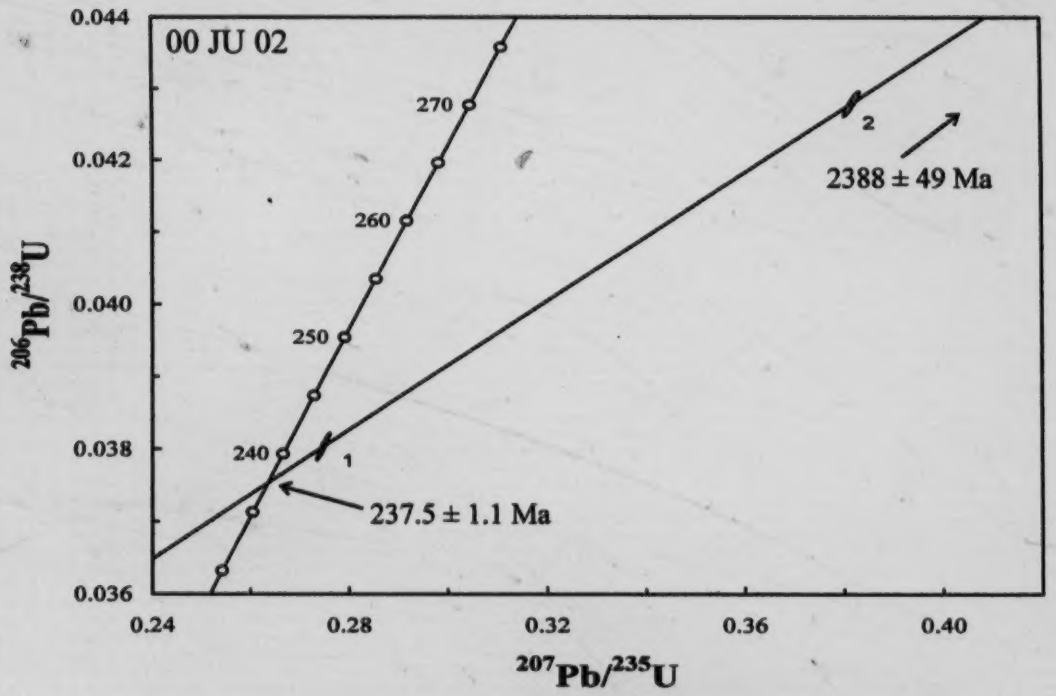


Figure 2-9: U-Pb concordia plot of zircons from 00 JU 02, the Silver Star tonalite. Error ellipses represent 2σ uncertainty.

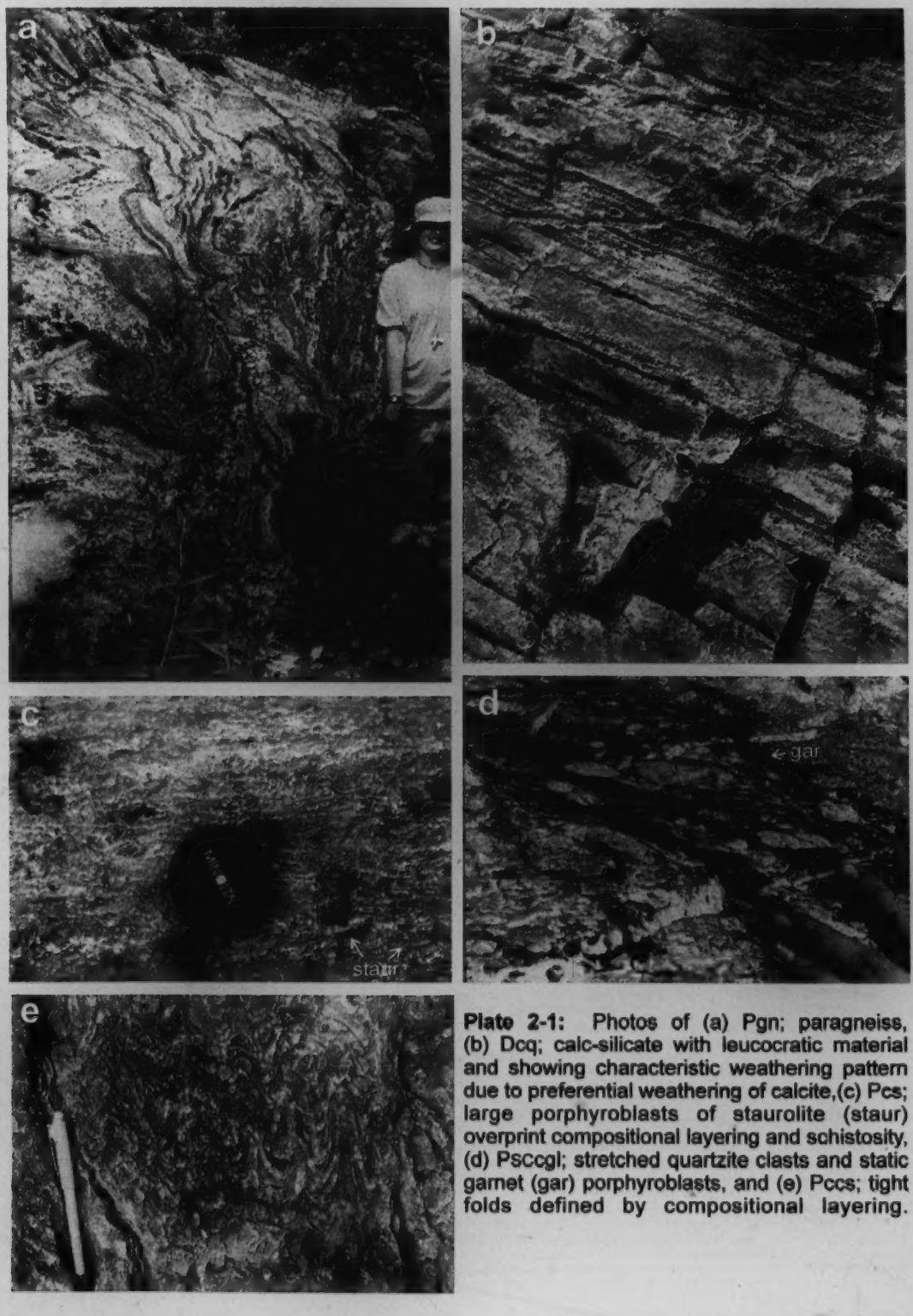


Plate 2-1: Photos of (a) Pgn; paragneiss, (b) Dcq; calc-silicate with leucocratic material and showing characteristic weathering pattern due to preferential weathering of calcite,(c) Pcs; large porphyroblasts of staurolite (staur) overprint compositional layering and schistosity, (d) Psccgl; stretched quartzite clasts and static garnet (gar) porphyroblasts, and (e) Pccs; tight folds defined by compositional layering.

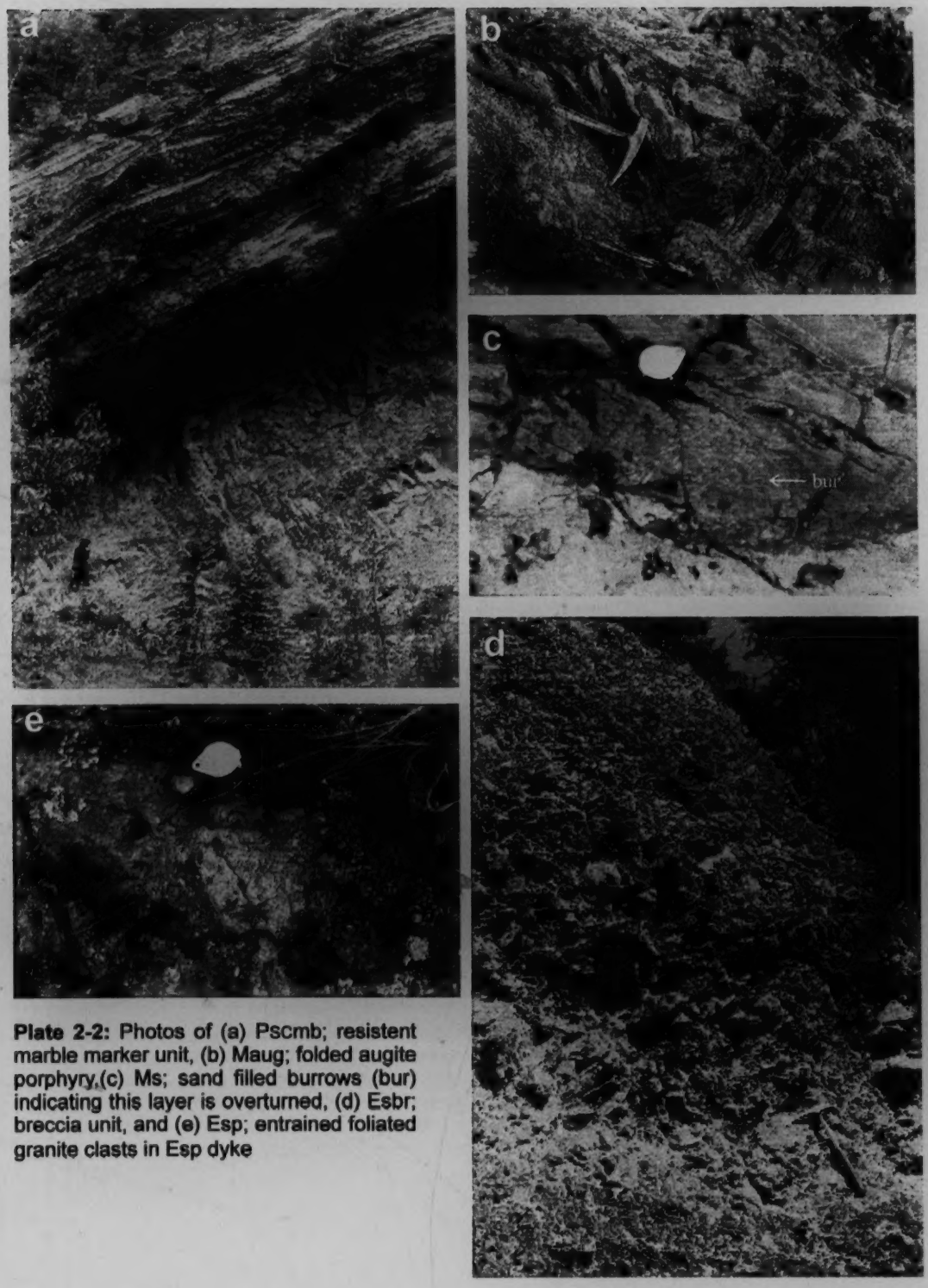


Plate 2-2: Photos of (a) Pscmb; resistent marble marker unit, (b) Maug; folded augite porphyry,(c) Ms; sand filled burrows (bur) indicating this layer is overturned, (d) Esbr; breccia unit, and (e) Esp; entrained foliated granite clasts in Esp dyke

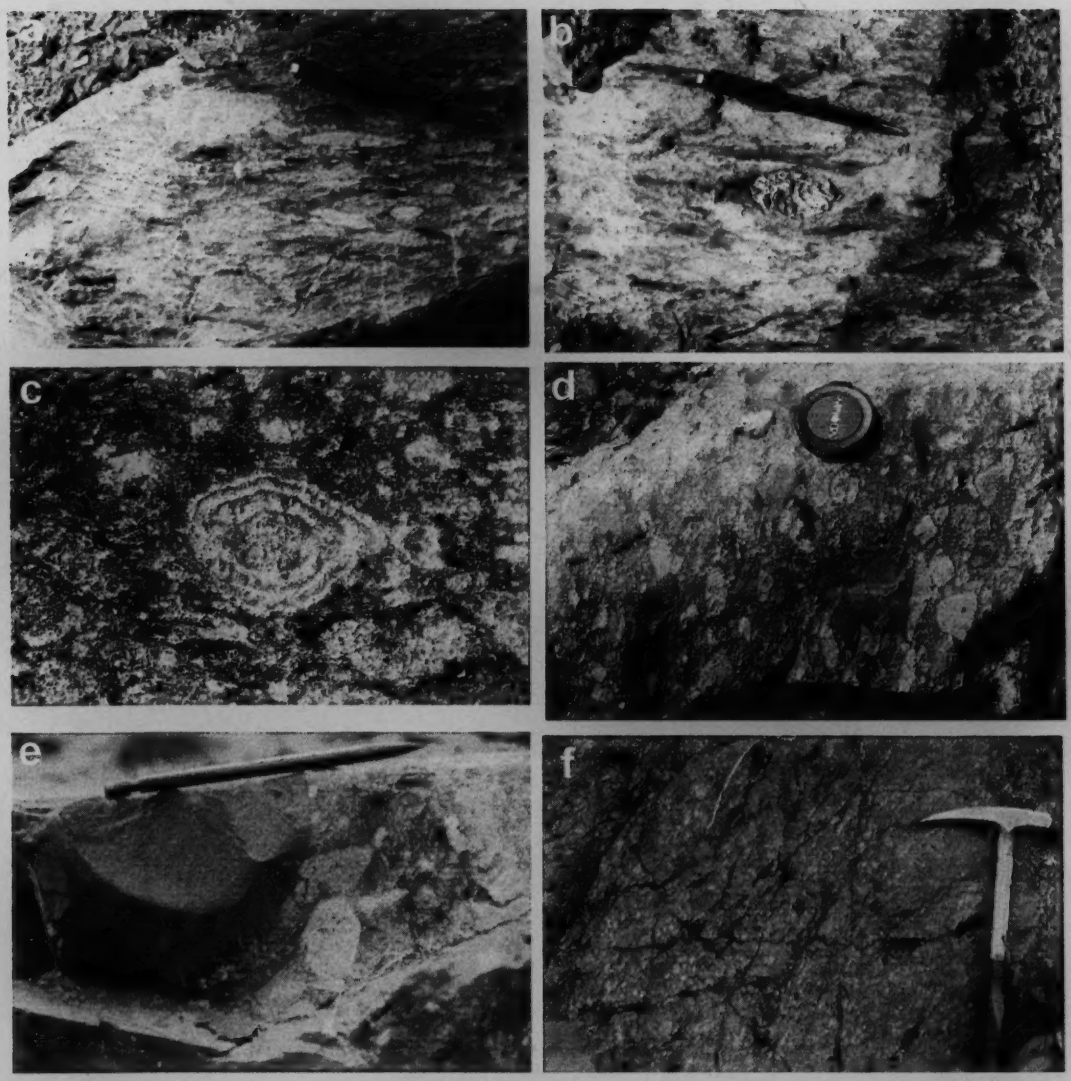


Plate 2-3: Photos of (a) Mcgl: JU SS CGL; clasts define a plane of flattening, (b) Mcgl: JU SS CGL; one granitoid cobble was observed at this locality, (c) Mcgl: JU SS CGL; photomicrograph of fusulinid within limestone clast (field of view = 3.2 mm), (d) Mcgl?: 99 LH 26; slate to metasandstone clasts, some slate clasts contain sandstone clasts, (e) Mcgl?: 99 LH 26; close-up photo showing contact with argillite, (f) Mcgl?: 99 LH 50; matrix supported conglomerate

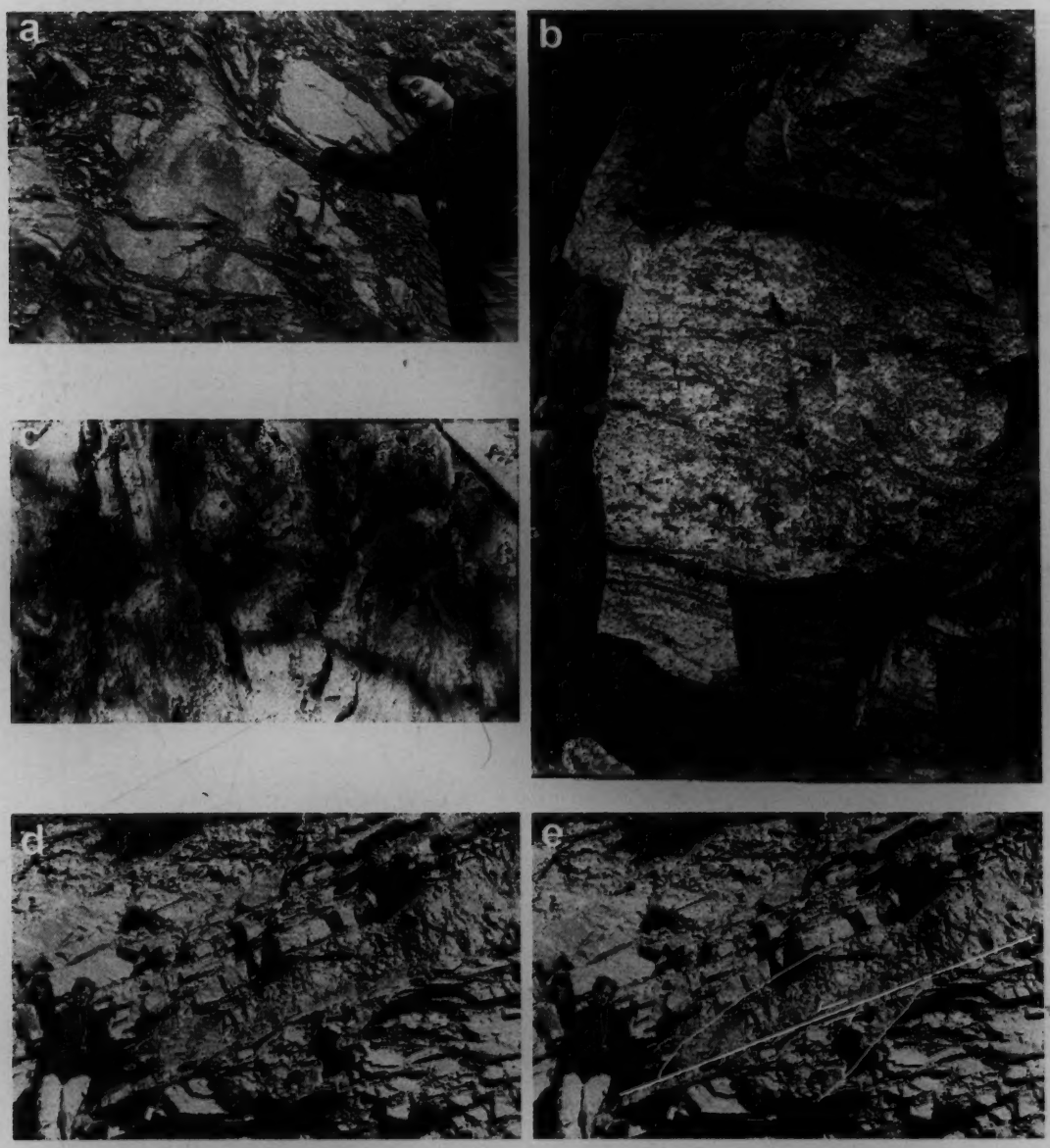


Plate 2-4: Photos of (a) Ms; two phases of folding, (b) Pba; mylonite, largely granitic and pegmatitic material with some schist, (c) Pccs; folding of layering, and near layer parallel cleavage,(d and e) Pmv; offset quartz vein along a normal fault, the base of the quartz vein is traced in yellow and the fault is traced in white

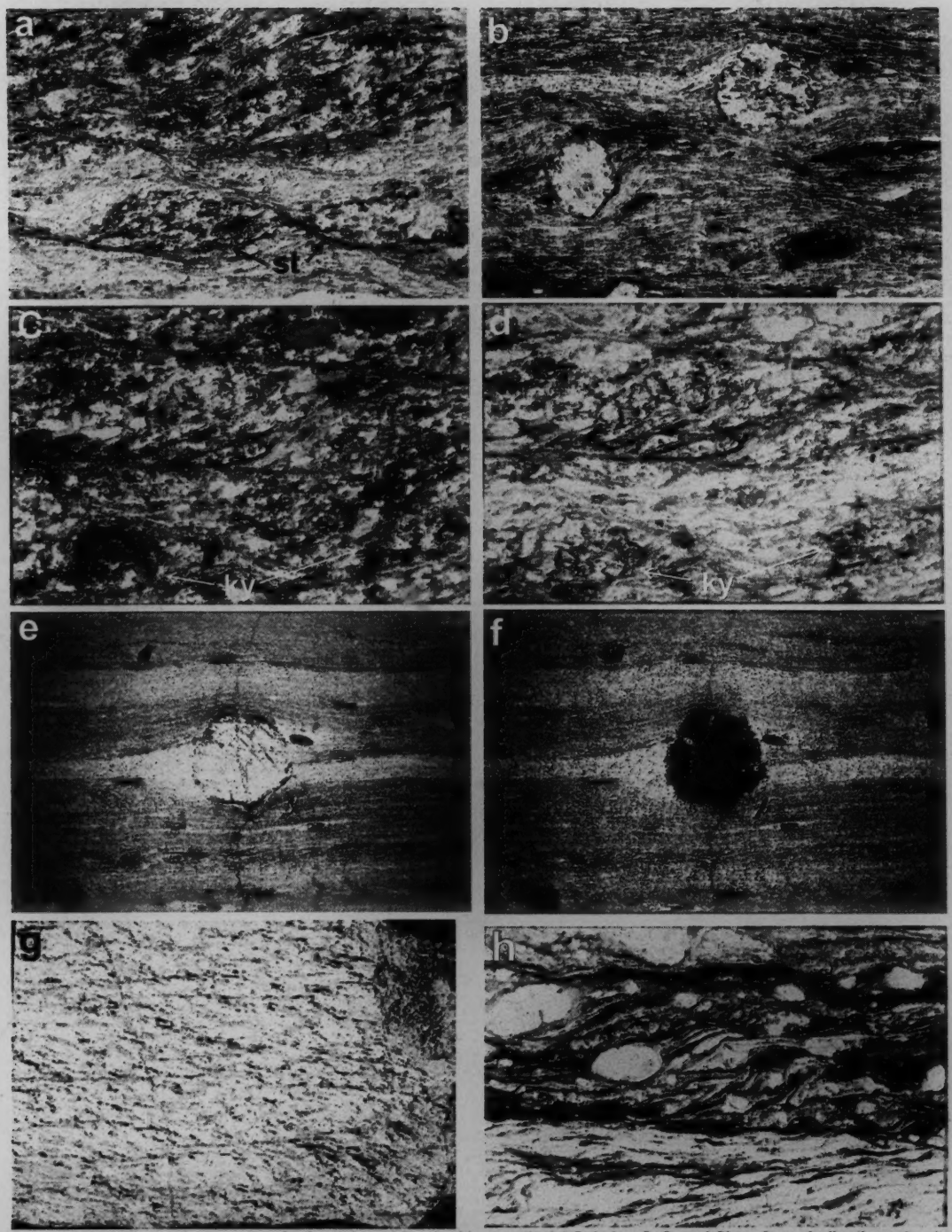


Plate 2-5: (a-f) Photomicrographs of oriented samples, looking north; (a) S. Lake; C, S, and C` surfaces indicating a top to the east sense of shear. Staurolite (st) porphyroblast is offset along C' surface. (b) 98 JU 290; δ-morphology garnet, indicating a top to the east sense of shear, (c) S. Lake; looking north, cross-polarized light, C, S, and C`surfaces indicating a top to the east sense of shear. Kyanite (ky) porphyroblast is offset along C` surface. (d) view of (c) under plane-polarized light, (e and f) 99 JU196A; looking north, plane- and cross-polarized light views of garnet porphyroblast, with quartz-rich layer suggesting top to the east sense of shear. (g) 98 JU 309: looking north well developed c-s fabric in a granite indicating top to the west sense of shear, (h) photomicrograph of Pba (unoriented) showing well developed ductile shear fabric. Fields of view are 3.2mm for a, b, c, d and f, 12.8 mm for e and f, and true scale for g.

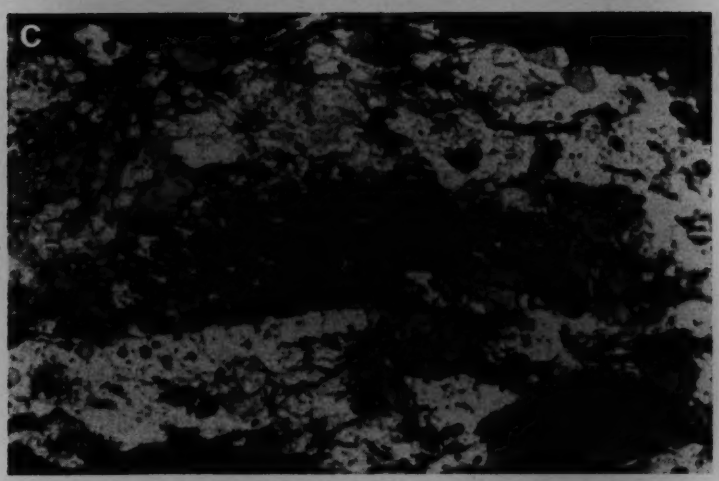


Plate 2-6: Photomicrographs of (a) Pcs; metamorphic porphyroblasts of staurolite (st) garnet (gar), and plagioclase (plag) overprint regional fabric defined by biotite and muscovite, cross-polarized view (b) Pba; relict kyanite (ky), and (c) Pba; relict staurolite. Fields of view are 12.8 mm for a and 3.2 mm for b and c.

Plate 2-7: Photos of zircons from sample 00 JU 01. (a) fraction 1, n = 48, (b) fraction 2, n = 9, (c) fraction 3, single grain. Fields of view are 1.8 mm, 1.38 mm, and 1.1 mm respectively.

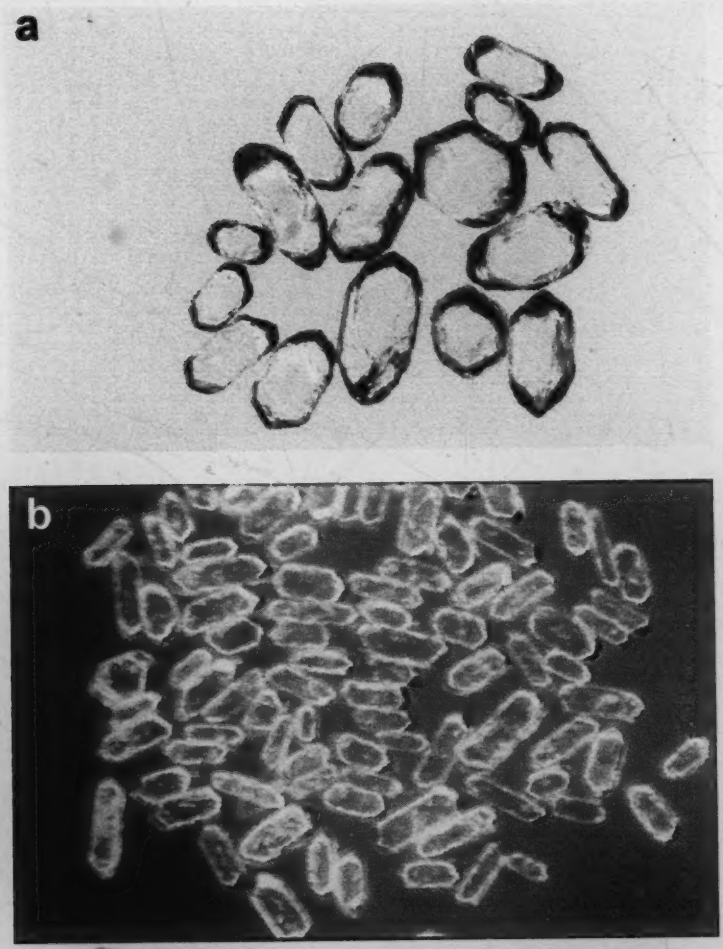


Plate 2-8: Photos of zircons from sample 00 JU 02. (a) fraction 1, n = 16, (b) fraction 2, n = 96. Field of view is 1.1 mm for (a) and (b).

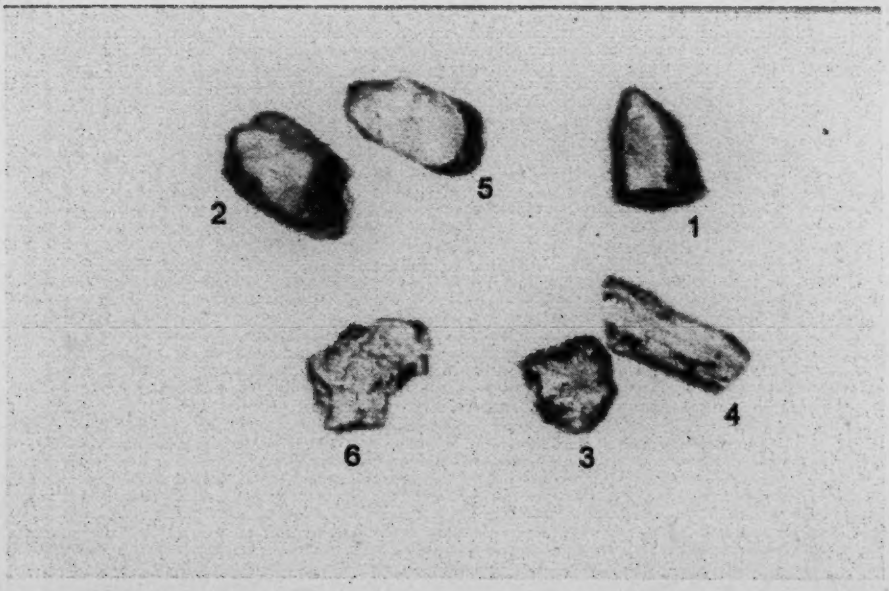


Plate 2-9: Photo of detrital zircons from unit Mcgl (JU SS CGL). Field of view is 1.1 mm. Fractions are as labelled. Zircon 6 was not analyzed.

Appendix 2-1: Station Locations

Station	UTM Easting	Northing
98JU0001	356791	5596456
98JU0002	356107	5595508
98JU0006b	352733	5589804
98JU0012	348859	5588284
98JU0014	349115	5587921
98JU0015	351136	5596017
98JU0016	351197	5596117
98JU0017	351267	5596110
98JU0018	351184	5595821
98JU0019	351154	5595581
98JU0020	351207	5595285
98JU0021	351294	5594840
98JU0022	351185	5594796
98JU0023	351026	5594058
98JU0024	350993	5593954
98JU0025	351075	5593841
98JU0025b	351297	5594116
98JU0026	351167	5593503
98JU0027	351071	5593203
98JU0028	349986	5592764
98JU0028b	349978	5592652
98JU0029	349983	5592605
98JU0030	349968	5592497
98JU0031	350016	5592452
98JU0032	350034	5592497
98JU0032b	350155	5592563
98JU0033	350195	5592520
98JU0034	350251	5592482
98JU0034b	350307	5592460
98JU0035	350352	5592495
98JU0036	350389	5592522
98JU0037	350459	5592542
98JU0037b	350449	5592568
98JU0037c	350585	5592545
98JU0037d	350699	5592563
98JU0038	350977	5595904
98JU0039	350859	5592664
98JU0040	350836	5592617
98JU0041	351893	5592800
98JU0042	351872	5592634
98JU0043	353284	5592509
98JU0044	353313	5592364
98JU0045	351667	5592576
98JU0048	348989	5589570
98JU0092	350022	5590660

Station	UTM Easting	Northing
98JU0049	349863	5589440
98JU0050	349948	5589332
98JU0051	349824	5589363
98JU0052	349530	5589545
98JU0053	349479	5589035
98JU0054	349548	5588875
98JU0055	349681	5588352
98JU0056	349738	5588408
98JU0057	349910	5588463
98JU0058	349926	5589006
98JU0059	350010	5589015
98JU0060	349991	5589103
98JU0061	349921	5589223
98JU0062	349936	5589081
98JU0063	349581	5589236
98JU0064	349550	5589121
98JU0065	348467	5590776
98JU0066	348965	5590571
98JU0067	348972	5590519
98JU0068	349075	5590537
98JU0069	349141	5590583
98JU0070	349285	5590608
98JU0071	349684	5590483
98JU0072	349810	5590444
98JU0073	349864	5590594
98JU0074	349951	5590457
98JU0075	357916	5597951
98JU0076	357581	5597882
98JU0076b	356700	5596707
98JU0077	354242	5595730
98JU0078	354074	5593195
98JU0079	353949	5593038
98JU0080	353783	5592833
98JU0081	354040	5592746
98JU0082	354184	5592659
98JU0083	348974	5591277
98JU0084	349200	5591389
98JU0085	349491	5591219
98JU0086	349885	5591052
98JU0087	349913	5591110
98JU0088	349975	5591022
98JU0089	349956	5590951
98JU0090	349961	5590907
98JU0091	349993	5590817
98JU0141	352687	5590317

98JU0093	350084	5590725
98JU0094	350114	5590759
98JU0095	350061	5590828
98JU0096	350073	5590937
98JU0097	350110	5590931
98JU0098	351337	5595601
98JU0099	351437	5595775
98JU0100	351464	5595682
98JU0101	351526	5595730
98JU0102	351607	5595615
98JU0103	351850	5595581
98JU0104	352067	5595584
98JU0105	352216	5595612
98JU0106	352297	5595548
98JU0107	352569	5595656
98JU0108	352675	5595604
98JU0109	352071	5595897
98JU0110	350925	5592473
98JU0110b	351062	5592536
98JU0111	351295	5592444
98JU0112	351320	5592345
98JU0113	351451	5592364
98JU0114	351476	5592246
98JU0115	351657	5592151
98JU0116	351755	5592080
98JU0117	351946	5592106
98JU0118	352150	5592174
98JU0119	351995	5592150
98JU0120	352071	5592222
98JU0121	352191	5592250
98JU0122	352200	5592366
98JU0123	352254	5592526
98JU0124	349930	5591287
98JU0125	350087	5591230
98JU0126	350164	5591231
98JU0127	350353	5591171
98JU0128	350459	5591071
98JU0129	350730	5591153
98JU0130	350919	5591077
98JU0131	350974	5591027
98JU0132	351232	5591002
98JU0133	351569	5591038
98JU0134	351582	5591031
98JU0135	351968	5591075
98JU0137	350707	5591688
98JU0138	350379	5591899
98JU0139	350214	5591753
98JU0140	353440	5590672
98JU0193	354381	5589026

98JU0142	352104	5589701
98JU0143	351448	5589242
98JU0144	351377	5589051
98JU0145	351571	5589337
98JU0146	351896	5589435
98JU0148	351477	5594736
98JU0149	351611	5594716
98JU0150	351716	5594545
98JU0151	352001	5594532
98JU0152	352074	5594416
98JU0153	352960	5593609
98JU0153b	353152	5593534
98JU0154	353018	5593381
98JU0156	354324	5590037
98JU0157	354279	5589152
98JU0158	354249	5588821
98JU0159	354392	5588065
98JU0160	347806	5589614
98JU0161	348029	5589445
98JU0162	348104	5589538
98JU0163	348310	5589252
98JU0164	348366	5589234
98JU0165	348489	5589355
98JU0166	348767	5588776
98JU0167	348451	5588491
98JU0168	348988	5588516
98JU0169	348964	5588415
98JU0170	348961	5588306
98JU0171	348998	5588297
98JU0172	349167	5588351
98JU0173	349121	5588395
98JU0174	347882	5589668
98JU0175	347897	5589433
98JU0176	347922	5589341
98JU0178	348172	5589030
98JU0179	348199	5589026
98JU0180	348186	5589229
98JU0181	348274	5588932
98JU0182	348204	5588693
98JU0183	348267	5588579
98JU0184	347890	5588772
98JU0186	354317	5589028
98JU0187	354221	5589082
98JU0188	353423	5588974
98JU0189	353589	5588809
98JU0190	353552	5588890
98JU0191	354598	5589232
98JU0192	354495	5589504
98JU0240	355193	5592537

98JU0194	354362	5588759
98JU0195	355007	5588536
98JU0196	354950	5588482
98JU0197	354587	5587874
98JU0198	355157	5590660
98JU0199	355487	5591051
98JU0200	355379	5590876
98JU0201	355112	5590515
98JU0202	355015	5590335
98JU0203	354880	5590221
98JU0204	354737	5590138
98JU0205	354682	5590110
98JU0206	354673	5589979
98JU0207	354849	5589286
98JU0208	354805	5589264
98JU0210	354721	5588858
98JU0211	355031	5588876
98JU0212	355293	5589034
98JU0213	355326	5589129
98JU0214	355320	5589143
98JU0215	352041	5588756
98JU0216	352191	5588643
98JU0217	352091	5588641
98JU0218	351927	5589113
98JU0219	351999	5589213
98JU0220	351834	5589495
98JU0221	352679	5589119
98JU0222a	352838	5590149
98JU0222b	352933	5590213
98JU0222c	352931	5590199
98JU0222d	353186	5590378
98JU0222e	353694	5591007
98JU0223	353525	5591287
98JU0224	353333	5591466
98JU0225	354220	5591381
98JU0226	354138	5591543
98JU0227	354205	5591599
98JU0228	354343	5591674
98JU0229	354527	5591484
98JU0230	354911	5591630
98JU0231	354885	5591812
98JU0232	354768	5591963
98JU0233	354687	5592033
98JU0234	354843	5591899
98JU0236	355094	5591719
98JU0237	355088	5591833
98JU0238	355246	5592005
98JU0239	355283	5592154
98JU0293	350646	5582781

98JU0241	355303	5592762
98JU0242	355420	5593101
98JU0243	355255	5593252
98JU0244	354911	5592497
98JU0245	354705	5592716
98JU0246	354368	5593031
98JU0247	352374	5588292
98JU0248	352260	5587849
98JU0249	351918	5587607
98JU0250	351121	5587292
98JU0251	351468	5587346
98JU0252	352552	5587396
98JU0253	354441	5587955
98JU0254	353102	5587487
98JU0255	353396	5587879
98JU0257	354180	5591997
98JU0258	354233	5592217
98JU0259a	354321	5592568
98JU0259b	354448	5592520
98JU0260	349497	5579007
98JU0261	350803	5580038
98JU0262	352117	5580473
98JU0263	352728	5580405
98JU0264	353446	5580315
98JU0265	353310	5579645
98JU0266	353439	5580105
98JU0267	350770	5580176
98JU0268	350977	5580136
98JU0269	350952	5580205
98JU0270	350645	5580171
98JU0271	350231	5580534
98JU0272	350194	5580423
98JU0273	350124	5580464
98JU0274	350237	5580556
98JU0274b	350267	5580552
98JU0281	350424	5580710
98JU0282	351783	5581626
98JU0283	352237	5581900
98JU0284	352893	5581410
98JU0285	352720	5582093
98JU0286	350203	5581047
98JU0287	350233	5581509
98JU0288	350527	5582085
98JU0288B	350524	5582159
98JU0289	350493	5582310
98JU0290	350614	5582435
98JU0291	350616	5582540
98JU0292	350724	5582533
98JU0344a	342855	5576091

98JU0294	350560	5582780
98JU0295	350363	5582480
98JU0296	350390	5582433
98JU0297	350425	5582231
98JU0298	350447	5581901
98JU0299	350217	5581358
98JU0300	350124	5581476
98JU0301	350048	5581520
98JU0302	350056	5581422
98JU0303	350035	5581347
98JU0304	350002	5581312
98JU0305	350076	5581130
98JU0306	350030	5581027
98JU0307	349985	5580814
98JU0308	349931	5580790
98JU0309	349916	5580770
98JU0310	349865	5580786
98JU0311	349810	5580744
98JU0312	349788	5580710
98JU0313	349758	5580640
98JU0314	349605	5580730
98JU0315	349635	5580570
98JU0316	349605	5580388
98JU0317	349383	5580176
98JU0318	350198	5580779
98JU0319	350230	5580769
98JU0320	350347	5580772
98JU0321	350088	5580526
98JU0322	349957	5580637
98JU0323	349733	5580573
98JU0324	349714	5580607
98JU0325	349344	5580193
98JU0326	349289	5580209
98JU0327	349202	5580234
98JU0328	349216	5580270
98JU0329	349235	5580311
98JU0330	349225	5580390
98JU0331	349236	5580518
98JU0332	349328	5580530
98JU0334a	349263	5580769
98JU0334b	349268	5580816
98JU0335	349420	5580867
98JU0337	342493	5575053
98JU0338	343966	5575558
98JU0339	346441	5575655
98JU0340	347625	5575317
98JU0341	343733	5578244
98JU0342	342961	5578335
98JU0405	348771	5583013

98JU0344b	353077	5587400
98JU0345	346734	5583012
98JU0346	346718	5583041
98JU0347	346724	5583081
98JU0348	346674	5583211
98JU0349	346672	5583350
98JU0350	346628	5583462
98JU0351	346587	5583469
98JU0352	346519	5583426
98JU0353	346219	5583592
98JU0354	346121	5584356
98JU0355a	345960	5584818
98JU0355b	345614	5584627
98JU0356	345974	5584950
98JU0357	346023	5585312
98JU0358	346322	5586668
98JU0359	345822	5586785
98JU0360	345707	5580027
98JU0361	346183	5580109
98JU0363	348918	5582875
98JU0363b	348932	5582831
98JU0365	349122	5583034
98JU0366	349031	5583128
98JU0367	349079	5583314
98JU0369	349244	5583347
98JU0373	348971	5583578
98JU0375	352155	5581525
98JU0376	349960	5580348
98JU0377	349730	5579950
98JU0378	346842	5578870
98JU0390	345324	5579065
98JU0391	345011	5579630
98JU0392	345047	5580627
98JU0393	345094	5580768
98JU0394	345154	5580968
98JU0395	345366	5580996
98JU0396a	347679	5581753
98JU0396b	348715	5582610
98JU0397a	348239	5582588
98JU0397b	348810	5582824
98JU0398a	348436	5582522
98JU0398b	348267	5582760
98JU0399	346439	5582632
98JU0400	346370	5582977
98JU0401	346114	5583792
98JU0402	346249	5583241
98JU0403	346883	5578926
98JU0404	346124	5579020
98JU0455	350894	5582282

98JU0407	349750	5581023
98JU0408	349927	5581116
98JU0409	349835	5581287
98JU0410	349799	5581421
98JU0411	349749	5581405
98JU0412	349875	5581526
98JU0413	349934	5581544
98JU0414	349716	5581686
98JU0415	349649	5581613
98JU0416	349550	5581499
98JU0417	349499	5581328
98JU0418	349465	5581156
98JU0419	349448	5581068
98JU0420	349474	5581036
98JU0421	349662	5580772
98JU0422	349729	5580825
98JU0423	349756	5580938
98JU0424	345492	5580834
98JU0425	345511	5580726
98JU0426	345430	5580520
98JU0427	345508	5580401
98JU0428	355120	5595262
98JU0429	353102	5590809
98JU0430	352836	5590569
98JU0431	352675	5589614
98JU0432	352376	5589727
98JU0433	352785	5589772
98JU0435	354878	5591627
98JU0436	350286	5581509
98JU0437	350334	5581884
98JU0438	350418	5582010
98JU0439	350131	5582135
98JU0440	350001	5582164
98JU0441	349978	5582101
98JU0442	349862	5582598
98JU0443a	349619	5582951
98JU0443b	349919	5583231
98JU0444	350224	5583621
98JU0445	350573	5583668
98JU0446	350790	5583582
98JU0447	351025	5583260
98JU0448	351051	5583192
98JU0449	351337	5583178
98JU0450	351240	5582736
98JU0451	351171	5582929
98JU0452	351180	5582791
98JU0453	351078	5582461
98JU0454	350793	5582400
98JU0510	354695	5582357

98JU0456	350957	5582404
98JU0457	350991	5582512
98JU0458	350820	5583129
98JU0459	350705	5583085
98JU0460	350480	5582530
98JU0462	349368	5582208
98JU0463	349545	5582298
98JU0464	349447	5582287
98JU0465	349240	5582299
98JU0467	349084	5582251
98JU0468	348962	5582093
98JU0469	348867	5581666
98JU0470	349058	5581644
98JU0471	349152	5581544
98JU0472	349182	5581637
98JU0473	349173	5581712
98JU0475	349308	5581532
98JU0476	349509	5581608
98JU0477	349780	5581658
98JU0478	349533	5580888
98JU0479	349489	5580946
98JU0480	349362	5581073
98JU0481	349384	5581275
98JU0482	349489	5581326
98JU0483	349321	5581416
98JU0484	349206	5581122
98JU0485	349213	5580905
98JU0486	349241	5580828
98JU0487	349381	5580828
98JU0488	349398	5580936
98JU0489	349481	5580863
98JU0490	349591	5580760
98JU0491	349427	5580896
98JU0492	349221	5580824
98JU0493	349786	5580562
98JU0494	353053	5581691
98JU0498	353248	5581940
98JU0499	353506	5582511
98JU0501	354153	5582709
98JU0502	354303	5582600
98JU0503	354362	5582820
98JU0504	354363	5583036
98JU0505	354524	5582981
98JU0506	354571	5582968
98JU0507	354583	5582832
98JU0508	354760	5582733
98JU0508b	355112	5582569
98JU0509	354932	5582373
98JU0584	353102	5581311

98JU0511	355457	5583050
98JU0512	355002	5582964
98JU0513	353512	5582936
98JU0513b	352766	5581880
98JU0513c	352559	5582095
98JU0513d	352053	5581679
98JU0513e	351479	5581643
98JU0513f	350946	5581020
98JU0513g	350800	5580765
98JU0514	350893	5581290
98JU0515	350800	5581410
98JU0516	350763	5581750
98JU0517	350910	5581971
98JU0518	351077	5582354
98JU0519	351372	5582464
98JU0520	350673	5581896
98JU0531	352185	5583363
98JU0532	352018	5583701
98JU0534	352010	5583829
98JU0535	352338	5584268
98JU0536	352209	5584914
98JU0537	352282	5584923
98JU0538	352951	5586051
98JU0539	353427	5586340
98JU0560	350707	5580454
98JU0561	350733	5580285
98JU0562	351260	5580223
98JU0563	351293	5580120
98JU0564	351676	5580000
98JU0565	351866	5580074
98JU0566	352125	5580191
98JU0567	352215	5580336
98JU0568	352339	5580858
98JU0569	352371	5581070
98JU0570	352501	5581594
98JU0571	352185	5581348
98JU0572	351884	5581114
98JU0573	351716	5580815
98JU0574	351414	5580667
98JU0575	351374	5580649
98JU0576	351267	5580562
98JU0577	351153	5580821
98JU0578	350917	5580810
98JU0579	350817	5580820
98JU0580	350642	5580880
98JU0581	350523	5580862
98JU0582	353413	5580885
98JU0583	353100	5581310
99LH0002	359108	5573412

98JU0585	353086	5581255
98JU0586	353164	5581313
98JU0587	353175	5581319
98JU0588	353270	5581370
98JU0589	353224	5581500
98JU0590	353072	5581458
98JU0591	352826	5581255
98JU0592	352814	5581083
98JU0593	374802	5589855
98JU0594	375410	5590844
98JU0595	375733	5591225
98JU0596	376117	5592767
98JU0597	376009	5599081
98JU0598	378619	5607180
98JU0599	379250	5607933
98JU0600	379769	5608841
98JU0601	381748	5614500
98JU0602	381750	5614482
98JU0603	359086	5573505
98JU0604	359170	5573212
98JU0605	357740	5575212
98JU0606	356644	5576320
98JU0607	356395	5576442
98JU0608	358661	5576402
98JU0609	358975	5576878
98JU0610	358975	5578189
98JU0611	360450	5577126
98JU0612	360791	5576333
98JU0613	362154	5578300
98JU0614	362049	5578462
98JU0615	361369	5577761
98JU0616	342477	5577909
98JU0617	360652	5581071
98JU0617b	360558	5580765
98JU0618	350565	5580613
98JU0619	360572	5580620
98JU0620	360226	5581613
98JU0621	359481	5580965
98JU0622	359015	5580525
98JU0623	360023	5580282
98JU0624	360871	5584978
98JU0625	361161	5585652
98JU0626	360485	5586358
98JU0627	360078	5586654
98JU0628	359831	5587895
98JU0629	359112	5595482
98JU0630	359690	5597294
99LH0001	362120	5576390
99LH0053	359637	5578719

99LH0003	358950	5572685
99LH0004	357170	5576388
99LH0005	356516	5576455
99LH0006	356152	5576358
99LH0007	355519	5576455
99LH0008	355194	5576441
99LH0009	356496	5576656
99LH0010	357024	5576593
99LH0011	357332	5576754
99LH0012	357316	5577657
99LH0013	357145	5577750
99LH0014	357287	5577938
99LH0015	357558	5577371
99LH0016	359703	5575476
99LH0017	359564	5575616
99LH0018	359407	5575698
99LH0019	359374	5575836
99LH0020	359503	5576375
99LH0021	357380	5576732
99LH0022	357593	5576584
99LH0024	358553	5576208
99LH0025	358930	5576895
99LH0026	358958	5577483
99LH0027	358524	5577202
99LH0028	358547	5578061
99LH0029	358639	5578189
99LH0030	358285	5578635
99LH0031	358175	5578098
99LH0032	357780	5578456
99LH0033	357898	5578901
99LH0034	360321	5577352
99LH0035	360671	5576482
99LH0036	360969	5576422
99LH0037	360107	5574548
99LH0038	360031	5575610
99LH0039	360084	5576186
99LH0040	360043	5576422
99LH0041	361733	5579199
99LH0042	361424	5579302
99LH0043	361809	5579376
99LH0044	361561	5579736
99LH0045	361414	5580486
99LH0046	361830	5579142
99LH0047	362027	5578527
99LH0048	361731	5578342
99LH0049	361628	5578005
99LH0050	360191	5578367
99LH0051	359962	5578894
99JU0044	349171	5569020

99LH0054	359408	5578488
99LH0056	362351	5577737
99LH0057	362486	5577818
99LH0058	362555	5578417
99LH0059	362796	5579915
99LH0060	362192	5576569
99LH0061	360465	5576898
99LH0062	359500	5570100
99JU0001	344678	5569698
99JU0002	343923	5570123
99JU0004	343768	5570436
99JU0005	344187	5571604
99JU0007	347455	5569435
99JU0008	348031	5569392
99JU0009	348396	5569842
99JU0010	348300	5570210
99JU0011	348173	5570549
99JU0012	348323	5570285
99JU0013	348508	5570125
99JU0014	350338	5570259
99JU0015	350700	5570298
99JU0016	350866	5570465
99JU0017	351321	5569647
99JU0018	352084	5568011
99JU0019	352125	5567946
99JU0020	352375	5567889
99JU0021	352432	5567962
99JU0022	352719	5568542
99JU0023	352303	5573047
99JU0024	352809	5573320
99JU0026	351034	5574945
99JU0027	350041	5576266
99JU0028	350256	5576670
99JU0029	349546	5575615
99JU0030	349610	5575984
99JU0031	351738	5576381
99JU0032	351445	5576381
99JU0033	352374	5576709
99JU0034	348526	5569763
99JU0035	348700	5569829
99JU0036	349007	5569747
99JU0037	348961	5569714
99JU0038	348908	5569703
99JU0039	348843	5569687
99JU0040	348796	5569612
99JU0041	348747	5569490
99JU0042	348776	5569433
99JU0043	348919	5569324
99JU0094	342833	5570640

99JU0045	349203	5569313
99JU0046	349277	5569242
99JU0047	349354	5569184
99JU0048	349702	5569033
99JU0049	349929	5569164
99JU0051	353323	5574730
99JU0052	350961	5569533
99JU0053	351032	5569361
99JU0054	351307	5568414
99JU0055	351384	5568126
99JU0056	351120	5568292
99JU0057	351054	5568320
99JU0058	350834	5568126
99JU0059	350718	5568315
99JU0060	351046	5567981
99JU0061	351115	5568085
99JU0062	351109	5567879
99JU0063	347837	5569123
99JU0064	347843	5569022
99JU0065	351416	5569927
99JU0066	351617	5569834
99JU0067	351695	5569821
99JU0068	351710	5569913
99JU0069	351686	5569960
99JU0070	351810	5570031
99JU0071	351965	5570004
99JU0072	352032	5569990
99JU0073	352255	5569939
99JU0074	352215	5569834
99JU0075	352111	5569562
99JU0076	352040	5569470
99JU0077	351984	5569812
99JU0078	341932	5570179
99JU0079	341978	5570341
99JU0080	342582	5572038
99JU0081	342580	5571957
99JU0082	342603	5571717
99JU0083	342508	5571061
99JU0084	342543	5570895
99JU0085	342628	5571056
99JU0086	342729	5571288
99JU0087	342998	5571854
99JU0088	343107	5571609
99JU0089	343390	5571443
99JU0090	343185	5571651
99JU0091	342846	5571040
99JU0092	342965	5570838
99JU0093	342911	5570745
99JU0145	344575	5568557

99JU0095	342957	5572865
99JU0096	346395	5573224
99JU0097	346729	5572764
99JU0098	347724	5572156
99JU0099	348156	5572314
99JU0100	348287	5572383
99JU0101	343148	5572481
99JU0102	342731	5572187
99JU0103	342808	5572180
99JU0104	342751	5572507
99JU0105	342965	5572136
99JU0106	343067	5572130
99JU0107	343154	5572093
99JU0108	343448	5571839
99JU0109	343554	5571773
99JU0110	343629	5571731
99JU0111	343774	5571821
99JU0112	343599	5571864
99JU0113	343848	5572615
99JU0114	344195	5572756
99JU0115	344611	5573339
99JU0116	344489	5573120
99JU0117	343516	5572495
99JU0118	343600	5572465
99JU0119	343451	5572450
99JU0120	343336	5572427
99JU0121	343239	5572414
99JU0122	343149	5572424
99JU0123	343084	5567738
99JU0124	343343	5567740
99JU0125	343591	5567730
99JU0126	343743	5567873
99JU0127	344034	5568770
99JU0128	344313	5569388
99JU0129	344347	5569329
99JU0130	344484	5569370
99JU0131	344560	5569058
99JU0132	344616	5569008
99JU0133	344658	5569046
99JU0134	344701	5569079
99JU0135	344843	5569029
99JU0136	344879	5568804
99JU0138	345064	5568744
99JU0140	345273	5568716
99JU0141	345094	5568695
99JU0142	345000	5568494
99JU0143	345034	5568596
99JU0144	344776	5568583
99JU0196	347489	5570644

99JU0146	344525	5568470
99JU0147	344135	5568090
99JU0149	344056	5568070
99JU0150	343914	5567922
99JU0151	343888	5568073
99JU0152	342335	5569163
99JU0153	342557	5569117
99JU0154	342693	5569088
99JU0155	342834	5569140
99JU0156	342901	5569097
99JU0157	343112	5569242
99JU0158	343210	5569122
99JU0159	344037	5569024
99JU0160	343754	5568873
99JU0161	343654	5568590
99JU0162	343532	5568772
99JU0163	343375	5568831
99JU0164	343270	5568731
99JU0165	343223	5568679
99JU0166	342769	5568429
99JU0167	342461	5568568
99JU0168	342450	5568398
99JU0169	342335	5568482
99JU0171	344393	5571564
99JU0172	343681	5570701
99JU0173	343733	5570548
99JU0174	343149	5570555
99JU0175	343054	5570290
99JU0176	343057	5569984
99JU0177	343075	5569948
99JU0178	343612	5571487
99JU0179	343574	5571206
99JU0180	346301	5571353
99JU0181	346311	5571453
99JU0182	346276	5571595
99JU0183	346537	5571658
99JU0184	346139	5571656
99JU0185	346039	5571499
99JU0186	346479	5571278
99JU0187	346625	5571178
99JU0188	346571	5571090
99JU0189	346650	5571151
99JU0190	346660	5571160
99JU0191	345927	5571653
99JU0192	346897	5570470
99JU0193	346972	5570476
99JU0194	347053	5570463
99JU0195	347562	5570542
99JU0245	345409	5568559

99JU0197	345587	5570533
99JU0198	345720	5570500
99JU0199	345434	5570595
99JU0200	345260	5570674
99JU0201	345246	5570751
99JU0202	345176	5570740
99JU0203	343546	5569668
99JU0204	342962	5569795
99JU0205	342962	5569795
99JU0206	342994	5569905
99JU0207	342702	5570518
99JU0208	344645	5570015
99JU0209	345141	5569372
99JU0210	345136	5568807
99JU0211	345290	5568817
99JU0212	345368	5568836
99JU0213	345489	5568814
99JU0214	345439	5568847
99JU0215	346257	5568779
99JU0216	346353	5568794
99JU0217	346391	5568789
99JU0218	346450	5568883
99JU0219	350859	5570866
99JU0220	350839	5570940
99JU0221	350314	5570813
99JU0222	350124	5570800
99JU0223	350092	5570913
99JU0224	349983	5571052
99JU0225	349688	5571584
99JU0226	349187	5571562
99JU0227	347789	5571985
99JU0228	345776	5568696
99JU0229	345550	5568638
99JU0230	345723	5568613
99JU0231	345735	5568563
99JU0232	345553	5568533
99JU0233	345731	5568534
99JU0234	345935	5568431
99JU0235	345414	5568297
99JU0236	345423	5568215
99JU0237	345378	5568079
99JU0238	345334	5567896
99JU0239	345154	5568076
99JU0240	345257	5568203
99JU0241	345159	5568327
99JU0242	345307	5568378
99JU0243	345380	5568522
99JU0244	345390	5568544
99JU0294	348375	5568714

99JU0246	346535	5568744
99JU0247	346491	5568537
99JU0248	346540	5568075
99JU0249	346317	5568078
99JU0250	346328	5567939
99JU0251	346312	5567814
99JU0252	345927	5567342
99JU0253	345720	5567234
99JU0254	345575	5567155
99JU0255	345503	5567067
99JU0256	345253	5567351
99JU0257	344893	5567336
99JU0258	344907	5567423
99JU0259	344692	5567521
99JU0260	344584	5567549
99JU0261	344433	5567725
99JU0262	344044	5567614
99JU0263	344001	5567498
99JU0264	344086	5567446
99JU0265	344081	5567524
99JU0266	344111	5567611
99JU0267	343827	5567512
99JU0268	345483	5567314
99JU0269	345370	5567409
99JU0270	345513	5567465
99JU0271	345634	5567563
99JU0272	345723	5567653
99JU0273	345739	5567695
99JU0274	345832	5567665
99JU0275	345985	5567681
99JU0276	346081	5567736
99JU0277	346225	5567646
99JU0278	346091	5567877
99JU0279	346178	5567948
99JU0280	346059	5567988
99JU0281	345936	5567977
99JU0282	345804	5568038
99JU0283	345727	5568064
99JU0284	345620	5568102
99JU0285	345601	5568006
99JU0286	345443	5568019
99JU0287	345509	5567960
99JU0288	345428	5567920
99JU0289	345435	5567760
99JU0290	345484	5567685
99JU0291	345427	5567602
99JU0292	345378	5567536
99JU0293	348242	5568843
99JU0343	346043	5568527

99JU0295	348499	5568647
99JU0296	348648	5568823
99JU0297	348765	5568970
99JU0298	348888	5568871
99JU0299	348918	5568813
99JU0300	348993	5568785
99JU0301	349086	5568801
99JU0302	349185	5568859
99JU0303	349241	5568799
99JU0304	349385	5568824
99JU0305	349444	5568832
99JU0306	349516	5568867
99JU0307	349723	5568771
99JU0308	349694	5568414
99JU0309	349793	5568335
99JU0310	349848	5568168
99JU0311	349793	5568039
99JU0312	357786	5575345
99JU0313	358103	5575795
99JU0314	358284	5576243
99JU0315	358409	5576420
99JU0316	358566	5576784
99JU0317	358723	5576933
99JU0318	358804	5576998
99JU0319	358865	5577283
99JU0320	358928	5577272
99JU0321	359041	5577526
99JU0322	358953	5577828
99JU0323	351335	5567788
99JU0324	351029	5567844
99JU0325	351057	5567968
99JU0326	350949	5567940
99JU0327	350616	5568158
99JU0328	350526	5568277
99JU0329	350461	5568360
99JU0330	350301	5568596
99JU0331	350354	5568840
99JU0332	350706	5567830
99JU0333	352125	5567712
99JU0334	352067	5567872
99JU0335	352331	5567826
99JU0336	352458	5567851
99JU0337	352783	5567984
99JU0338	353094	5568077
99JU0339	346216	5568197
99JU0340	345778	5568220
99JU0341	345714	5568137
99JU0342	345872	5568338
99JU0393	359063	5571676

99JU0344	351594	5570348
99JU0345	351862	5570646
99JU0346	352428	5570514
99JU0347	352212	5570437
99JU0348	355134	5572085
99JU0349	354354	5572326
99JU0350	354701	5572654
99JU0351	355431	5573292
99JU0352	355195	5574509
99JU0353	355418	5574519
99JU0354	355365	5574659
99JU0355	352116	5570559
99JU0356	351959	5568574
99JU0357	351843	5569025
99JU0359	346492	5567627
99JU0360	346644	5567702
99JU0361	346389	5567131
99JU0362	346344	5567257
99JU0363	346123	5567145
99JU0364	346263	5566998
99JU0365	346387	5567016
99JU0366	346527	5567018
99JU0367	346537	5567227
99JU0368	346894	5567327
99JU0369	346828	5567540
99JU0370	346776	5567415
99JU0371	346911	5567628
99JU0372	346916	5567749
99JU0373	346988	5567738
99JU0374	346772	5567762
99JU0375	346661	5567972
99JU0376	353912	5568094
99JU0377	353673	5568145
99JU0378	353281	5568132
99JU0379	353253	5568371
99JU0380	353464	5569099
99JU0381	353945	5568557
99JU0382	354070	5568478
99JU0383	354020	5568076
99JU0384	353924	5567945
99JU0385	354811	5568100
99JU0386	354881	5568165
99JU0387	355042	5568288
99JU0388	355363	5568309
99JU0389	355213	5567890
99JU0390	355180	5567777
99JU0391	354801	5567427
99JU0392	359473	5571953
99JU0445	347842	5567888

99JU0394	346684	5568494
99JU0395	346495	5568536
99JU0396	346676	5568444
99JU0397	346902	5568385
99JU0398	346974	5568492
99JU0399	346928	5568275
99JU0400	346965	5568328
99JU0401	347088	5568327
99JU0402	347160	5568429
99JU0403	347274	5568392
99JU0404	347166	5568212
99JU0405	347420	5568363
99JU0406	347462	5568548
99JU0407	347505	5568589
99JU0408	347527	5568648
99JU0409	347555	5568702
99JU0410	347514	5568792
99JU0411	347648	5568807
99JU0412	347792	5568793
99JU0413	347738	5568763
99JU0414	347724	5568537
99JU0415	347767	5568553
99JU0416	347743	5568441
99JU0417	347800	5568406
99JU0419	347184	5567966
99JU0420	347162	5567911
99JU0421	347141	5567863
99JU0422	346979	5568027
99JU0423	346982	5567891
99JU0424	346457	5568390
99JU0426	352283	5569403
99JU0427	352648	5569607
99JU0428	352485	5569665
99JU0429	352478	5569746
99JU0430	352493	5569846
99JU0432	352979	5569754
99JU0433	353438	5569952
99JU0434	353013	5569706
99JU0435	352415	5568822
99JU0436	352820	5569000
99JU0437	348094	5568647
99JU0438	347936	5568509
99JU0439	348147	5568495
99JU0440	348205	5568453
99JU0441	348425	5568410
99JU0442	348248	5568324
99JU0443	348218	5568266
99JU0444	348117	5568051
99JU0494	357889	5572232

99JU0446	347903	5567874
99JU0447	348102	5567900
99JU0448	348235	5567851
99JU0449	348118	5567822
99JU0450	347733	5567748
99JU0451	347675	5567898
99JU0452	347732	5567621
99JU0453	347646	5567934
99JU0454	347600	5568081
99JU0455	348025	5568421
99JU0456	347448	5569180
99JU0457	347377	5569074
99JU0458	347237	5568890
99JU0459	347158	5569018
99JU0460	347146	5569126
99JU0461	346725	5569456
99JU0462	346852	5569672
99JU0463	347121	5569632
99JU0464	347173	5569724
99JU0465	347316	5569711
99JU0466	345030	5571944
99JU0467	344649	5571804
99JU0468	344522	5571947
99JU0469	344315	5572253
99JU0470	343749	5570722
99JU0471	344402	5571984
99JU0472	344042	5571114
99JU0473	344228	5572069
99JU0474	344336	5572325
99JU0475	344419	5572459
99JU0476	344634	5572532
99JU0477	344766	5572642
99JU0478	344937	5572779
99JU0479	345039	5572802
99JU0480	345096	5572985
99JU0481	345307	5572988
99JU0482	344845	5573196
99JU0483	344795	5573000
99JU0484	344819	5573332
99JU0485	356245	5570257
99JU0486	355813	5570058
99JU0487	358976	5568617
99JU0488	359077	5573250
99JU0489	358987	5572991
99JU0490	358748	5572808
99JU0491	358552	5572194
99JU0492	358391	5572121
99JU0493	358098	5572190
99JU0545	356184	5567178

99JU0495	358056	5572650
99JU0496	358214	5572661
99JU0497	358294	5572683
99JU0498	358301	5572910
99JU0499	358289	5572987
99JU0500	357906	5573503
99JU0501	357902	5573610
99JU0502	357914	5573673
99JU0504	358748	5568358
99JU0506	358575	5572409
99JU0507	361563	5583451
99JU0508	361573	5583623
99JU0508b	361437	5583639
99JU0509	361211	5583631
99JU0510	361106	5583628
99JU0511	360994	5583702
99JU0512	360880	5583686
99JU0513	360046	5583377
99JU0514	359933	5583555
99JU0515	359609	5583750
99JU0516	358249	5583848
99JU0517	358085	5583821
99JU0518	360807	5583001
99JU0519	361071	5582585
99JU0520	360781	5582459
99JU0521	360336	5582430
99JU0522	361058	5583240
99JU0523	361259	5583112
99JU0524	361453	5582976
99JU0525	361595	5583221
99JU0526	361665	5582713
99JU0527	361600	5582717
99JU0528	360838	5581335
99JU0530	362265	5582960
99JU0531	362372	5582982
99JU0532	362493	5583275
99JU0533	358728	5566849
99JU0534	351747	5568704
99JU0535	361944	5586289
99JU0536	361416	5584543
99JU0537	361326	5585045
99JU0538	361009	5585227
99JU0539	361195	5585884
99JU0540	360289	5586565
99JU0541	357878	5589060
99JU0542	357760	5592856
99JU0543	357638	5593378
99JU0544	356489	5567037
99JU0598	348474	5567865

99JU0546	356581	5567355
99JU0547	356430	5567536
99JU0549	356772	5567482
99JU0550	357055	5567506
99JU0551	357214	5567543
99JU0552	357465	5567489
99JU0553	357582	5567438
99JU0554	357634	5567296
99JU0555	357666	5567258
99JU0556	357706	5567210
99JU0557	357719	5567187
99JU0558	357714	5567090
99JU0559	357710	5566967
99JU0560	357702	5566918
99JU0561	357757	5566916
99JU0562	357791	5566967
99JU0564	358501	5566951
99JU0565	358297	5566980
99JU0566	358503	5567029
99JU0567	358437	5567079
99JU0569	358395	5567154
99JU0570	358298	5567162
99JU0571	358311	5567242
99JU0572	357788	5567839
99JU0573	357979	5567397
99JU0574	357994	5567304
99JU0575	358069	5566984
99JU0576	358132	5566891
99JU0577	358372	5567537
99JU0578	358393	5567452
99JU0579	351170	5572266
99JU0580	351331	5572291
99JU0581	349543	5572687
99JU0582	349012	5571450
99JU0583	348919	5571403
99JU0584	348859	5571285
99JU0585	349933	5570657
99JU0586	349913	5570715
99JU0587	349966	5570757
99JU0588	349966	5570827
99JU0589	349909	5570988
99JU0591	348991	5568120
99JU0592	348928	5568190
99JU0593	348840	5567964
99JU0594	348759	5568022
99JU0595	348789	5567932
99JU0596	348754	5567764
99JU0597	348595	5567821
99JU0650	356406	5582928

99JU0599	348366	5567789
99JU0600	348420	5567735
99JU0601	348318	5567697
99JU0602	348051	5567685
99JU0603	348170	5567631
99JU0604	348055	5567571
99JU0605	348060	5567622
99JU0606	347953	5567531
99JU0608	347685	5567309
99JU0609	347777	5567294
99JU0610	347980	5567437
99JU0611	348061	5567386
99JU0612	348172	5567434
99JU0613	348272	5567491
99JU0614	348546	5567671
99JU0615	348755	5567651
99JU0618	349030	5568330
99JU0619	349176	5568460
99JU0620	349355	5568447
99JU0621	349470	5568267
99JU0622	349421	5568541
99JU0623	349283	5568589
99JU0624	349161	5568623
99JU0625	349110	5568707
99JU0626	349031	5568657
99JU0627	348985	5568620
99JU0628	348613	5568598
99JU0629	348672	5568579
99JU0630	348562	5568557
99JU0631	348537	5568457
99JU0632	348529	5568403
99JU0633	348490	5568338
99JU0634	348435	5568204
99JU0635	348377	5568173
99JU0636	348312	5568124
99JU0637	348248	5568057
99JU0638	348359	5568040
99JU0639	348721	5568066
99JU0640	346437	5573366
99JU0641	346320	5573573
99JU0642	346176	5573659
99JU0643	345848	5574048
99JU0644	353828	5580747
99JU0645	355384	5580745
99JU0646	356235	5582028
99JU0647	356348	5582105
99JU0648	356429	5582570
99JU0649	356359	5582669
99JU0700	349561	5586663

99JU0651	356341	5583078
99JU0652	356562	5583267
99JU0653	356786	5583657
99JU0654	356624	5583744
99JU0655	356422	5583855
99JU0656	356424	5583860
99JU0657	356403	5584249
99JU0658	356013	5584468
99JU0659	355866	5584515
99JU0660	355644	5584504
99JU0661	355478	5584450
99JU0662	355228	5584155
99JU0663	354948	5584044
99JU0664	354669	5583689
99JU0665	351690	5589427
99JU0666	352589	5589644
99JU0667	392744	5589818
99JU0668	352779	5590600
99JU0669	353061	5590905
99JU0670	353333	5590988
99JU0671	354045	5591481
99JU0672	353571	5591883
99JU0674	353338	5592320
99JU0675	353254	5592353
99JU0676	353482	5592901
99JU0677	353558	5592985
99JU0678	352865	5580480
99JU0679	352600	5580464
99JU0680	352536	5580477
99JU0681	352351	5580542
99JU0682	352000	5580
99JU0683	351621	5580
99JU0684	351526	5580
99JU0685	351416	5580223
99JU0686	351312	5580212
99JU0687	351207	5580224
99JU0688	350989	5580203
99JU0689	350864	5580123
99JU0690	353150	5584558
99JU0691	352696	5586035
99JU0692	352333	5586241
99JU0693	350762	5586498
99JU0694	350657	5586564
99JU0695	350387	5586327
99JU0696	350304	5586548
99JU0697	350110	5586503
99JU0698	350074	5586
99JU0699	350008	5586571

99JU0701	349558	5586233
99JU0702	349517	5585847
99JU0703	349556	5585711
99JU0704	349554	5585568
99JU0705	349534	5585382
99JU0706	349352	5585562
99JU0707	349316	5585629
99JU0708	349199	5585662
99JU0709	349053	5585636
99JU0710	348911	5585583
99JU0711	348519	5585948
99JU0712	348248	5586353
99JU0713	348245	5586650
99JU0714	348173	5587032
99JU0715	347918	5587123
99JU0716	348024	5587603
99JU0717	347857	5587322
99JU1tri	357024	5591554
99JU2tri	357186	5591552
99JU3tri	357314	5591662
99JU4tri	357211	5590593
00JU0001	342483	5568991
00JU0002	350094	5580482
S. Lake	350231	5580534

Appendix 2-2: Structural Measurements

Legend

Foliations

s-bed: bedding/compositional layering; sufol: cleavage/schistosity;
s-fol1: secondary cleavage/schistosity/crenulation cleavage, ju: joints;
s-fol2: third cleavage/shistosity; suplw: slickenside surface; fu: mylonitic foliation
buax: axial plane

Lineations

l-1: mineral lineation; lu: streching lineation, l-fold1:fold axis; l-int1: intersection lineation;
l-ss: slickenline lineation;

Station	Structure	Azimuth	Dip		Station	Structure	Azimuth	Dip
98JU0005	sufol	359	56		98JU0083	sufol	278	52
98JU0005	s-bed	56	50		98JU0085	l-1	11	65
98JU0005	s-fol1	321	89		98JU0085	sufol	270	66
98JU0005	s-bed	359	56		98JU0086	l-ss	255	60
98JU0023	sufol	346	81		98JU0086	suplw	212	60
98JU0023	sufol	318	80		98JU0098	sufol	339	84
98JU0025	sufol	355	86		98JU0110	sufol	333	73
98JU0028	sufol	155	75		98JU0110b	sufol	350	74
98JU0028	sufol	140	76		98JU0111	sufol	343	80
98JU0028b	sufol	315	66		98JU0112	sufol	338	78
98JU0031	sufol	0	73		98JU0114	sufol	336	73
98JU0031	sufol	0	80		98JU0115	sufol	321	59
98JU0032	sufol	6	81		98JU0117	sufol	342	86
98JU0032b	sufol	347	89		98JU0117	sufol	356	68
98JU0033	sufol	329	85		98JU0118	sufol	8	56
98JU0034b	ju	194	21		98JU0119	sufol	352	71
98JU0034b	sufol	336	79		98JU0120	sufol	352	75
98JU0035	sufol	330	60		98JU0121	sufol	346	81
98JU0037c	sufol	13	86		98JU0125	sufol	90	84
98JU0040	sufol	335	72		98JU0125	ju	180	82
98JU0048	l-1	331	53		98JU0128	sufol	287	69
98JU0048	sufol	264	51		98JU0129	sufol	300	53
98JU0049	sufol	274	62		98JU0129	ju	22	85
98JU0050	sufol	275	51		98JU0131	sufol	274	78
98JU0051	sufol	266	62		98JU0132	sufol	298	69
98JU0054	sufol	310	58		98JU0137	sufol	292	73
98JU0054	sufol	321	74		98JU0140	sufol	71	61
98JU0055b	sufol	297	84		98JU0140	s-bed	358	58
98JU0055b	sufol	304	80		98JU0141	sufol	310	59
98JU0056	sufol	305	74		98JU0142	sufol	280	67
98JU0060	sufol	304	55		98JU0143	s-fol1	219	58
98JU0067	s-bed	282	59		98JU0143	sufol	319	65
98JU0067	sufol	282	59		98JU0143	s-bed	319	65
98JU0070	sufol	276	61		98JU0143	sufol	312	69
98JU0074	sufol	278	80		98JU0143	sufol	310	67
98JU0077	ju	187	41		98JU0143	s-fol2	52	65

98JU0144	s-bed	308	50	98JU0203	sufol	14	49
98JU0144	sufol	205	70	98JU0204	sufol	52	48
98JU0144	ju	65	45	98JU0204	ju	175	72
98JU0151	sufol	168	62	98JU0205	sufol	53	48
98JU0157	sufol	255	67	98JU0207	sufol	300	53
98JU0159	sufol	25	36	98JU0208	sufol	300	53
98JU0160	sufol	262	51	98JU0208	l-l	141	15
98JU0162	sufol	272	70	98JU0213	sufol	180	61
98JU0162	l-l	103	19	98JU0213	sufol	295	49
98JU0163	sufol	290	62	98JU0214	sufol	75	68
98JU0164	sufol	328	50	98JU0215	sufol	299	51
98JU0166	sufol	310	30	98JU0216	sufol	295	61
98JU0167	sufol	308	34	98JU0218	sufol	290	57
98JU0167	l-l	94	24	98JU0218	sufol	290	57
98JU0167	sufol	305	42	98JU0221	sufol	293	71
98JU0168	sufol	308	38	98JU0227	sufol	315	63
98JU0168	sufol	287	40	98JU0237	sufol	100	78
98JU0169	sufol	312	38	98JU0237	sufol	103	76
98JU0169	sufol	312	30	98JU0238	sufol	102	47
98JU0169	lu	85	30	98JU0240	sufol	220	43
98JU0171	sufol	312	27	98JU0241	sufol	165	37
98JU0172	sufol	310	31	98JU0247	sufol	273	83
98JU0174	sufol	290	36	98JU0250	l-fold1	90	21
98JU0176	sufol	308	28	98JU0250	sufol	297	39
98JU0176	l-ss	77	29	98JU0250	l-fold1	90	21
98JU0178	s-bed	304	61	98JU0251	sufol	263	80
98JU0178	sufol	304	61	98JU0251	sufol	85	87
98JU0178	suplw	175	80	98JU0251	sufol	263	80
98JU0178	l-ss	153	74	98JU0254	sufol	284	78
98JU0181	sufol	265	39	98JU0259a	sufol	166	45
98JU0181	sufol	270	31	98JU0259a	l-int1	217	45
98JU0181b	sufol	301	32	98JU0259b	l-int1	219	72
98JU0181b	sufol	296	35	98JU0259b	sufol	144	67
98JU0186	sufol	263	78	98JU0260	suplw	12	20
98JU0187	sufol	292	85	98JU0260	lu	105	10
98JU0190	sufol	279	50	98JU0260	sufol	17	53
98JU0190	sufol	288	56	98JU0260	sufol	41	25
98JU0191	sufol	270	60	98JU0260	sufol	40	15
98JU0194	ju	200	55	98JU0260	l-ss	88	18
98JU0194	ju	341	50	98JU0261	sufol	0	48
98JU0197	sufol	30	70	98JU0261	sufol	10	49
98JU0197	l-l	80	55	98JU0263	sufol	136	73
98JU0198	sufol	314	76	98JU0263	s-bed	280	46
98JU0199	ju	186	68	98JU0265	sufol	72	48
98JU0199	sufol	97	79	98JU0265	ju	322	80
98JU0201	sufol	315	40	98JU0267	sufol	8	34
98JU0202	sufol	331	47	98JU0269	sufol	10	44
98JU0202	sufol	320	49	98JU0271	sufol	320	46
98JU0203	ju	124	84	98JU0274	sufol	339	51

98JU0274b	sufol	4	46		98JU0354	sufol	329	19
98JU0280	sufol	348	49		98JU0356	sufol	292	20
98JU0280	sufol	355	38		98JU0357	sufol	357	16
98JU0282	sufol	324	41		98JU0359	sufol	292	46
98JU0288	sufol	357	44		98JU0365	sufol	306	44
98JU0288	lu	97	49		98JU0366	sufol	354	35
98JU0289	sufol	12	48		98JU0366	lu	85	35
98JU0290	sufol	358	55		98JU0367	sufol	340	45
98JU0290	l-1	84	55		98JU0373	sufol	320	37
98JU0292	sufol	0	48		98JU0373	l-1	65	34
98JU0292	sufol	13	46		98JU0375	s-bed	180	73
98JU0292	l-1	90	46		98JU0376	sufol	330	38
98JU0293	sufol	5	53		98JU0377	sufol	17	53
98JU0294	sufol	10	44		98JU0392	sufol	283	63
98JU0300	sufol	325	31		98JU0398b	sufol	326	29
98JU0308	sufol	345	49		98JU0402	sufol	293	39
98JU0309	l-1	78	28		98JU0404	lu	74	21
98JU0309	sufol	1	33		98JU0404	sufol	19	25
98JU0309	sufol	355	34		98JU0405	lu	68	17
98JU0309	l-1	80	30		98JU0405	sufol	340	17
98JU0310	l-1	74	30		98JU0407	sufol	342	29
98JU0310	sufol	335	30		98JU0407	lu	83	30
98JU0311	sufol	328	52		98JU0409	sufol	333	52
98JU0312	sufol	320	45		98JU0413	sufol	2	38
98JU0313	sufol	331	55		98JU0413	lu	97	36
98JU0314	sufol	328	38		98JU0413	ju	205	64
98JU0316	sufol	352	41		98JU0417	sufol	339	54
98JU0318	sufol	56	14		98JU0417	lu	91	52
98JU0318	s-bed	56	14		98JU0420	sufol	342	51
98JU0319	sufol	32	62		98JU0422	sufol	2	40
98JU0319	l-1	98	57		98JU0423	l-1	87	57
98JU0320	sufol	32	44		98JU0423	sufol	4	55
98JU0320	l-ss	284	6		98JU0426	sufol	40	23
98JU0320	suplw	152	14		98JU0430	sufol	355	53
98JU0320	sufol	42	9		98JU0431	sufol	270	63
98JU0320	s-bed	91	21		98JU0435	sufol	127	60
98JU0322	sufol	345	36		98JU0438	sufol	15	37
98JU0322	l-1	77	33		98JU0440	lu	80	37
98JU0323	sufol	346	53		98JU0440	sufol	328	36
98JU0324	sufol	340	46		98JU0441	sufol	355	55
98JU0331	sufol	339	66		98JU0441	lu	90	55
98JU0333	sufol	350	41		98JU0442	l-1	90	49
98JU0334	sufol	354	38		98JU0442	sufol	337	51
98JU0335	sufol	337	51		98JU0443b	sufol	4	45
98JU0340	sufol	301	70		98JU0443b	lu	89	45
98JU0345	sufol	279	21		98JU0445	sufol	12	44
98JU0346	sufol	341	40		98JU0446	sufol	358	37
98JU0347	sufol	284	19		98JU0446	l-1	90	37
98JU0347	l-1	85	5		98JU0447	sufol	340	23

98JU0447	l-1	76	23	98JU0491	sufol	335	54
98JU0448	sufol	350	48	98JU0492	sufol	354	36
98JU0448	l-1	74	46	98JU0494	s-bed	7	44
98JU0449	sufol	333	48	98JU0494	s-bed	306	47
98JU0451	sufol	355	29	98JU0500	s-bed	323	57
98JU0451	l-1	87	29	98JU0501	s-bed	337	52
98JU0452	sufol	350	36	98JU0504	s-bed	315	15
98JU0453	sufol	350	45	98JU0505	s-bed	318	33
98JU0453	l-1	80	45	98JU0506	sufol	45	64
98JU0454	sufol	359	38	98JU0506	s-fol1	222	42
98JU0455	l-1	85	36	98JU0508a	sufol	288	41
98JU0455	sufol	356	36	98JU0508b	ju	110	50
98JU0456	sufol	25	44	98JU0508b	sufol	245	74
98JU0456	l-1	90	44	98JU0509	sufol	288	53
98JU0457	sufol	15	31	98JU0509	s-bed	95	10
98JU0457	l-1	85	30	98JU0510	sufol	42	35
98JU0458	sufol	345	48	98JU0511	sufol	285	8
98JU0458	l-1	80	48	98JU0512	sufol	288	64
98JU0459	l-1	85	46	98JU0513	ju	43	20
98JU0459	sufol	345	46	98JU0513b	ju	348	60
98JU0460	sufol	350	55	98JU0513b	ju	144	43
98JU0462	sufol	344	34	98JU0513d	sufol	3	45
98JU0463	lu	104	26	98JU0513e	s-bed	345	46
98JU0464	sufol	310	50	98JU0513f	sufol	2	31
98JU0464	sufol	340	41	98JU0513g	s-bed	30	39
98JU0465	sufol	344	35	98JU0514	sufol	43	41
98JU0468	sufol	359	64	98JU0514	l-1	79	35
98JU0470	sufol	340	30	98JU0515	s-bed	2	41
98JU0470	lu	107	23	98JU0516	sufol	2	55
98JU0470	sufol	333	41	98JU0517	sufol	4	42
98JU0471	sufol	338	53	98JU0518	sufol	5	31
98JU0473	sufol	341	42	98JU0518	l-1	84	29
98JU0474	sufol	345	35	98JU0519	sufol	20	39
98JU0474	sufol	334	40	98JU0520	sufol	15	76
98JU0475	sufol	340	33	98JU0531	sufol	264	77
98JU0476	sufol	341	76	98JU0531	sufol	53	48
98JU0476	sufol	333	40	98JU0538	sufol	86	75
98JU0477	sufol	356	34	98JU0538	s-bed	86	75
98JU0479	sufol	357	41	98JU0539	sufol	261	31
98JU0479	lu	94	36	98JU0560	sufol	10	71
98JU0480	sufol	335	53	98JU0560	sufol	8	73
98JU0481	sufol	329	54	98JU0560	sufol	5	75
98JU0483	sufol	338	35	98JU0561	sufol	21	59
98JU0486	sufol	351	18	98JU0562	sufol	356	45
98JU0487	sufol	336	51	98JU0562	l-1	106	45
98JU0488	sufol	338	45	98JU0562	ju	158	85
98JU0489	sufol	333	56	98JU0563	sufol	4	34
98JU0490	sufol	343	48	98JU0563	sufol	354	32
98JU0490	lu	85	41	98JU0605	s-bed	291	81

98JU0564	sufol	6	45		98JU0605	s-bed	122	89
98JU0565	sufol	359	50		98JU0605	sufol	6	70
98JU0565	l-1	68	50		98JU0607	sufol	15	36
98JU0566	sufol	354	34		98JU0607	sufol	34	34
98JU0566	l-1	88	34		98JU0607	sufol	10	38
98JU0566	l-1	92	45		98JU0610	sufol	49	51
98JU0566	s-fol1	131	38		98JU0611	fu	34	33
98JU0566	s-fol1	150	85		98JU0612	sufol	49	73
98JU0566	l-int1	75	30		98JU0615	s-bed	355	27
98JU0566	sufol	354	45		98JU0617	l-1	63	27
98JU0569	l-1	90	32		98JU0617	sufol	20	49
98JU0569	sufol	22	39		98JU0617b	sufol	30	47
98JU0571	sufol	1	55		98JU0617b	l-1	65	31
98JU0571	l-1	98	50		98JU0622	s-bed	4	61
98JU0573	sufol	13	54		98JU0623	sufol	108	18
98JU0575	s-bed	305	59		98JU0625	sufol	285	74
98JU0576	s-bed	327	48		98JU0625	sufol	265	75
98JU0577	sufol	25	40		98JU0626	s-bed	232	62
98JU0577	sufol	40	45		98JU0626	sufol	269	83
98JU0578	sufol	18	34		98JU0626	sufol	251	84
98JU0578	l-1	97	33		98JU0628	sufol	234	76
98JU0579	sufol	36	45		99LH0001	fu	55	62
98JU0580	sufol	13	72		99LH0004	sufol	69	28
98JU0581	sufol	70	49		99LH0004	sufol	75	32
98JU0581	lu	90	37		99LH0006	sufol	40	35
98JU0584	sufol	356	81		99LH0011	sufol	314	41
98JU0585	sufol	270	47		99LH0016	s-bed	335	65
98JU0586	l-1	357	28		99LH0016	sufol	291	87
98JU0586	sufol	357	28		99LH0016	s-bed	319	60
98JU0587	s-bed	355	68		99LH0016	sufol	283	81
98JU0587	sufol	345	90		99LH0016	ju	9	41
98JU0588	sufol	293	44		99LH0016	j	48	78
98JU0588	sufol	302	43		99LH0023	sufol	246	65
98JU0590	l-int1	92	49		99LH0023	sufol	246	65
98JU0590	sufol	342	55		99LH0025	s-bed	332	80
98JU0590	s-bed	14	62		99LH0025	s-bed	332	80
98JU0592	sufol	30	45		99LH0026	sufol	189	13
98JU0593	l-1	69	32		99LH0027	sufol	101	45
98JU0593	sufol	25	37		99LH0027	sufol	101	45
98JU0593	lu	69	32		99LH0029	sufol	40	52
98JU0593	sufol	25	37		99LH0029	sufol	27	45
98JU0594	sufol	312	32		99LH0029	sufol	47	45
98JU0595	sufol	285	90		99LH0030	ju	131	66
98JU0596	sufol	297	81		99LH0030	sufol	35	32
98JU0597	sufol	103	39		99LH0030	l-1	114	12
98JU0598	sufol	16	37		99LH0031	sufol	52	34
98JU0599	sufol	73	25		99LH0033	sufol	12	35
98JU0602	sufol	276	14		99LH0035	sufol	43	70
98JU0604	s-bed	282	72		99JU0046	subed	90	39

99LH0041	sufol	340	40		99JU0047	ju	80	89
99LH0044	sufol	340	35		99JU0047	ju	238	37
99LH0045	sufol	330	68		99JU0051	s-fol1	204	13
99LH0045	l-1	93	60		99JU0051	sufol	204	23
99LH0049	sufol	12	55		99JU0052	s-bed	85	52
99LH0052	sufol	190	42		99JU0054	ju	111	49
99LH0061	sufol	47	35		99JU0055	ju	323	60
99LH0061	sufol	25	34		99JU0055	ju	282	55
99LH0061	sufol	36	49		99JU0055	subed	205	55
99LH0061	l-1	134	35		99JU0060	subed	215	59
99JU0001	sufol	95	46		99JU0061	sufol	248	58
99JU0001	l-1	135	21		99JU0063	sufol	275	61
99JU0001	s-fol1	236	24		99JU0078	sufol	340	23
99JU0001	s-bed	90	37		99JU0079	s-bed	34	39
99JU0001	sufol	79	50		99JU0079	sufol	0	30
99JU0001	s-fol1	266	30		99JU0080	s-bed	14	31
99JU0001	suplw	67	39		99JU0081	sufol	37	44
99JU0001	l-1	125	28		99JU0081	ju	226	45
99JU0001	s-bed	100	49		99JU0082	sufol	51	46
99JU0004	s-fol1	119	70		99JU0085	ju	53	51
99JU0004	s-bed	109	75		99JU0087	s-bed	42	61
99JU0004	s-fol2	1	73		99JU0089	ju	320	87
99JU0004	s-bed	116	76		99JU0090	l-1	73	42
99JU0004	lu	288	40		99JU0090	sufol	1	44
99JU0004	lu	264	35		99JU0092	s-fol1	352	75
99JU0004	sufol	109	75		99JU0092	s-bed	114	36
99JU0004b	s-bed	38	70		99JU0092	l-1	250	25
99JU0005	s-bed	37	11		99JU0092	s-fol1	58	70
99JU0007	sufol	311	31		99JU0092	sufol	114	36
99JU0007	sufol	335	37		99JU0093	s-bed	52	30
99JU0007	sufol	330	36		99JU0093	s-fol1	18	87
99JU0007	sufol	301	41		99JU0093	s-fol1	33	28
99JU0007	sufol	281	40		99JU0093	sufol	98	29
99JU0008	sufol	257	65		99JU0093	l-1	228	22
99JU0009	s-bed	280	74		99JU0093	ju	52	30
99JU0015	s-bed	104	89		99JU0094	s-bed	90	45
99JU0015	s-bed	116	76		99JU0099	s-bed	286	87
99JU0017	s-bed	10	76		99JU0100	s-bed	297	82
99JU0018	sufol	13	56		99JU0103	sufol	303	60
99JU0024	s-bed	251	50		99JU0104	sufol	300	46
99JU0034	sufol	49	41		99JU0104	sufol	305	49
99JU0035	subed	116	10		99JU0104	lu	87	29
99JU0035	ju	130	68		99JU0106	l-1	87	29
99JU0035	ju	201	74		99JU0106	sufol	357	26
99JU0035	ju	86	51		99JU0107	l-1	111	29
99JU0037	subed	185	40		99JU0107	sufol	11	29
99JU0039	subed	172	23		99JU0108	s-bed	295	58
99JU0042	subed	189	81		99JU0110	sufol	291	73
99JU0045	subed	220	62		99JU0178	s-bed	30	29

99JU0117	sufol	316	32		99JU0191	s-fol1	123	79
99JU0117	l-1	74	32		99JU0203	ju	4	61
99JU0120	sufol	32	41		99JU0203	sufol	124	70
99JU0121	sufol	298	52		99JU0204	s-bed	86	50
99JU0122	sufol	326	75		99JU0205	sufol	191	74
99JU0124	ju	214	72		99JU0205	s-bed	108	70
99JU0124	sufol	101	62		99JU0207	s-bed	141	61
99JU0125	sufol	259	55		99JU0207	sufol	241	52
99JU0126	sufol	267	44		99JU0207	ju	46	68
99JU0129	sufol	116	79		99JU0209	s-bed	92	48
99JU0130	sufol	114	62		99JU0209	s-fol2	283	46
99JU0132	ju	49	79		99JU0209	s-fol1	179	58
99JU0132	ju	256	68		99JU0209	sufol	92	48
99JU0134	s-fol1	267	36		99JU0211	sufol	116	39
99JU0135	ju	21	79		99JU0212	s-fol1	348	56
99JU0135	ju	40	78		99JU0212	sufol	238	55
99JU0137	sufol	102	50		99JU0212	s-bed	112	55
99JU0138	s-fol1	334	69		99JU0213	s-bed	109	57
99JU0140	ju	224	40		99JU0213	sufol	223	54
99JU0141	ju	229	65		99JU0215	sufol	91	52
99JU0142	ju	254	65		99JU0215	s-fol1	235	55
99JU0144	ju	216	70		99JU0215	s-bed	91	52
99JU0144	ju	247	38		99JU0216	sufol	226	90
99JU0146	sufol	30	85		99JU0216	s-bed	110	33
99JU0152	ju	176	64		99JU0217	sufol	102	30
99JU0152	sufol	291	28		99JU0217	s-fol1	228	70
99JU0153	sufol	199	7		99JU0218	sufol	42	60
99JU0153	ju	210	74		99JU0218	s-bed	85	42
99JU0153	lu	80	5		99JU0218	s-fol1	266	41
99JU0154	sufol	293	21		99JU0219	s-fol1	8	84
99JU0154	ju	206	75		99JU0219	sufol	252	74
99JU0155	ju	217	79		99JU0219	s-bed	212	71
99JU0157	ju	122	84		99JU0220	sufol	85	42
99JU0157	sufol	279	51		99JU0220	s-fol1	311	70
99JU0157	sufol	280	56		99JU0220	sufol	305	53
99JU0158	sufol	276	46		99JU0220	s-bed	85	42
99JU0163	lu	99	1		99JU0220	s-fol1	37	82
99JU0163	ju	208	87		99JU0220	s-bed	305	53
99JU0163	sufol	90	12		99JU0225	s-bed	282	55
99JU0165	ju	187	80		99JU0229	ju	242	44
99JU0165	ju	245	59		99JU0229	sufol	95	52
99JU0166	ju	234	70		99JU0231	s-fol1	243	57
99JU0167	sufol	214	12		99JU0231	sufol	104	49
99JU0167	lu	264	10		99JU0231	ju	351	82
99JU0171	sufol	125	69		99JU0232	sufol	75	50
99JU0174	s-bed	104	56		99JU0232	s-fol1	251	38
99JU0177	s-fol1	209	87		99JU0233	s-fol1	26	80
99JU0177	sufol	96	49		99JU0233	sufol	251	38
99JU0233	sufol	84	46		99JU0262	sufol	67	48

99JU0234	s-fol1	243	61		99JU0262	s-bed	67	48
99JU0234	sufol	85	47		99JU0264	sufol	82	49
99JU0237	l-fold1	338	56		99JU0264	s-bed	82	49
99JU0237	sufol	100	39		99JU0264	s-fol1	328	72
99JU0238	sufol	92	44		99JU0265	s-bed	76	61
99JU0238	s-fol1	242	42		99JU0265	sufol	76	61
99JU0239	s-fol1	234	65		99JU0266	sufol	73	42
99JU0239	ju	350	68		99JU0267	s-bed	31	60
99JU0239	sufol	92	36		99JU0269	sufol	109	44
99JU0244	sufol	68	43		99JU0269	s-fol1	211	64
99JU0245	sufol	78	54		99JU0269	s-fol1	322	49
99JU0245	s-fol1	256	56		99JU0270	sufol	121	52
99JU0246	sufol	80	59		99JU0270	s-fol1	222	77
99JU0246	s-fol1	274	29		99JU0271	sufol	125	44
99JU0246	s-fol2	23	45		99JU0271	s-fol1	85	89
99JU0247	l-ss	133	11		99JU0272	sufol	155	44
99JU0247	suplw	83	24		99JU0272	s-fol1	222	77
99JU0248	sufol	86	48		99JU0273	sufol	143	64
99JU0248	s-fol1	281	48		99JU0273	s-fol1	46	86
99JU0249	s-fol1	152	25		99JU0273	s-fol1	120	7
99JU0249	sufol	84	48		99JU0274	sufol	99	64
99JU0250	s-fol1	12	79		99JU0274	s-fol1	353	50
99JU0250	s-fol1	30	77		99JU0274	s-fol1	226	41
99JU0250	s-fol1	15	75		99JU0275	sufol	97	54
99JU0250	sufol	84	30		99JU0275	s-fol1	223	46
99JU0250	sufol	86	47		99JU0276	s-fol1	212	72
99JU0252	s-fol1	210	25		99JU0276	sufol	95	76
99JU0252	s-bed	140	66		99JU0276	s-fol1	234	28
99JU0253	s-fol1	43	19		99JU0277	s-fol1	220	54
99JU0253	s-fol1	112	87		99JU0277	s-fol1	351	49
99JU0253	sufol	131	80		99JU0277	sufol	97	63
99JU0255	s-fol1	214	46		99JU0278	sufol	97	61
99JU0255	sufol	152	90		99JU0282	sufol	79	26
99JU0255	s-fol1	55	42		99JU0283	sufol	44	38
99JU0256	s-fol1	255	39		99JU0287	s-fol1	212	20
99JU0256	sufol	123	71		99JU0287	sufol	97	57
99JU0257	s-fol1	28	60		99JU0287	sufol	84	47
99JU0257	sufol	116	56		99JU0287	s-fol1	234	49
99JU0257	s-fol1	244	44		99JU0289	s-fol1	228	89
99JU0258	s-fol1	312	71		99JU0292	s-fol1	212	85
99JU0258	s-fol1	264	62		99JU0292	sufol	111	46
99JU0258	sufol	110	44		99JU0295	sufol	115	79
99JU0259	sufol	112	75		99JU0297	ju	1	90
99JU0259	sufol	128	82		99JU0297	sufol	294	74
99JU0260	sufol	99	60		99JU0297	ju	291	82
99JU0261	s-fol1	261	61		99JU0302	ju	129	45
99JU0262	s-fol1	202	78		99JU0302	ju	240	75
99JU0262	s-fol1	251	26		99JU0302	ju	188	29
99JU0304	ju	9	67		99JU0361	l-fold1	145	12

99JU0304	ju	192	34		99JU0361	l-fold1	289	8
99JU0312	sufol	246	65		99JU0361	l-fold1	124	23
99JU0313	sufol	246	65		99JU0361	buax	106	39
99JU0317	s-bed	332	80		99JU0362	sufol	119	57
99JU0317	sufol	332	80		99JU0362	s-fol1	230	72
99JU0319	s-bed	56	14		99JU0362	s-fol2	59	32
99JU0319	sufol	52	85		99JU0363	s-bed	134	90
99JU0319	s-bed	56	14		99JU0365	sufol	251	40
99JU0321	suplw	152	14		99JU0365	s-bed	112	75
99JU0321	s-bed	91	21		99JU0365	s-bed	12	65
99JU0321	l-ss	284	6		99JU0365	s-fol1	70	35
99JU0321	sufol	42	9		99JU0366	s-bed	132	66
99JU0331	ju	207	81		99JU0367	s-fol1	231	57
99JU0336	subed	0	24		99JU0367	l-fold1	216	15
99JU0340	s-fol1	238	38		99JU0367	sufol	53	58
99JU0340	sufol	76	48		99JU0368	sufol	58	31
99JU0341	s-fol1	33	84		99JU0369	s-bed	19	33
99JU0341	sufol	124	21		99JU0370	sufol	167	34
99JU0345	ju	64	31		99JU0370	s-bed	61	32
99JU0345	ju	264	57		99JU0383	sufol	25	25
99JU0348	sufol	349	31		99JU0386	sufol	308	55
99JU0349	s-bed	308	80		99JU0387	ju	187	81
99JU0349	ju	37	85		99JU0387	sufol	64	10
99JU0349	s-fol1	198	56		99JU0393	ju	125	80
99JU0349	sufol	312	70		99JU0393	ju	68	78
99JU0351	ju	9	82		99JU0393	ju	323	68
99JU0351	s-fol1	82	45		99JU0394	sufol	92	47
99JU0351	sufol	319	64		99JU0397	s-bed	359	61
99JU0351	s-bed	319	64		99JU0397	s-bed	67	35
99JU0351	s-bed	319	64		99JU0408	s-bed	297	65
99JU0351	s-fol1	82	45		99JU0410	sufol	61	70
99JU0352	sufol	338	62		99JU0410	sufol	317	72
99JU0352	sufol	235	49		99JU0412	l-fold1	87	61
99JU0352	s-bed	52	45		99JU0412	sufol	9	55
99JU0352	s-fol1	338	62		99JU0414	s-bed	165	59
99JU0352	sufol	235	49		99JU0416	s-bed	264	50
99JU0352	s-bed	52	45		99JU0417	ju	139	46
99JU0353	sufol	356	53		99JU0419	sufol	307	39
99JU0353	sufol	344	63		99JU0429	suflow	359	63
99JU0353	sufol	344	63		99JU0439	s-bed	193	84
99JU0354	s-bed	80	71		99JU0446	subed	295	86
99JU0354	sufol	80	71		99JU0447	s-bed	322	57
99JU0354	s-bed	80	71		99JU0456	sufol	251	34
99JU03547	s-bed	200	24		99JU0456	s-fol1	69	54
99JU0359	sufol	80	42		99JU0456	s-fol1	67	61
99JU0359	sufol	107	46		99JU0456	s-fol1	344	74
99JU0359	s-fol1	224	44		99JU0457	s-fol1	322	45
99JU0361	buax	118	56		99JU0457	sufol	249	81
99JU0457	sufol	244	82		99JU0495	sufol	116	49

99JU0458	sufol	57	52		99JU0496	sufol	170	76
99JU0458	s-fol1	303	48		99JU0496	s-fol1	0	50
99JU0459	s-fol1	291	46		99JU0496	ju	110	73
99JU0459	sufol	54	44		99JU0496	s-bed	265	50
99JU0460	sufol	251	77		99JU0500	sufol	0	77
99JU0462	sufol	274	65		99JU0500	s-bed	291	59
99JU0463	sufol	316	64		99JU0501	sufol	279	45
99JU0464	sufol	291	82		99JU0501	ju	166	57
99JU0465	sufol	299	82		99JU0501	ju	60	75
99JU0472	sufol	99	43		99JU0501	s-fol1	180	86
99JU0472	s-fol2	130	63		99JU0502	s-bed	90	80
99JU0472	s-fol1	219	73		99JU0506	sufol	309	38
99JU0475	sufol	11	47		99JU0506	s-fol1	254	41
99JU0475	sufol	109	61		99JU0509	ju	79	90
99JU0476	sufol	100	44		99JU0509	ju	115	68
99JU0480	sufol	320	79		99JU0509	ju	95	53
99JU0480	s-bed	72	55		99JU0510	s-fol1	100	46
99JU0484	s-fol1	301	54		99JU0510	sufol	280	45
99JU0484	s-bed	23	37		99JU0512	ju	106	47
99JU0484	sufol	180	73		99JU0512	ju	113	64
99JU0485	sufol	16	47		99JU0512	ju	216	74
99JU0485	ju	198	32		99JU0514	s-bed	282	60
99JU0485	l-1	110	46		99JU0514	s-bed	299	40
99JU0486	sufol	92	53		99JU0514	sufol	41	61
99JU0486	l-1	133	39		99JU0514	sufol	189	77
99JU0487	sufol	356	10		99JU0514	sufol	172	85
99JU0488	sufol	106	30		99JU0514	s-bed	172	85
99JU0488	s-fol1	226	72		99JU0515	s-fol1	236	43
99JU0488	s-bed	106	30		99JU0515	sufol	65	59
99JU0489	s-bed	289	82		99JU0515	s-fol1	325	72
99JU0490	s-fol1	209	80		99JU0515	s-bed	65	59
99JU0490	ju	233	35		99JU0516	s-fol1	146	28
99JU0490	s-bed	285	82		99JU0516	s-fol1	58	45
99JU0490	sufol	285	82		99JU0516	s-fol1	220	73
99JU0491	s-bed	287	86		99JU0516	sufol	311	63
99JU0492	s-fol1	7	87		99JU0517	sufol	315	62
99JU0492	s-bed	286	45		99JU0517	s-fol1	228	56
99JU0492	sufol	286	45		99JU0517	sufol	127	31
99JU0492	s-fol1	67	64		99JU0517	s-bed	315	62
99JU0493	sufol	168	88		99JU0518	sufol	288	28
99JU0493	sufol	54	56		99JU0518	s-fol1	211	89
99JU0493	s-bed	292	61		99JU0519	s-fol1	97	43
99JU0494	sufol	181	83		99JU0519	s-fol1	158	87
99JU0494	s-bed	275	55		99JU0519	sufol	297	45
99JU0494	ju	142	38		99JU0521	s-fol1	79	71
99JU0494	sufol	234	82		99JU0521	sufol	280	33
99JU0495	ju	203	23		99JU0523	sufol	314	45
99JU0495	ju	184	77		99JU0523	sufol	204	86
99JU0523	ju	114	59		99JU0560	sufol	100	80

99JU0526	ju	184	87		99JU0560	ju	171	81
99JU0526	ju	104	55		99JU0561	sufol	122	62
99JU0526	ju	278	44		99JU0561	s-fol1	138	70
99JU0527	s-fol1	165	60		99JU0562	sufol	118	65
99JU0527	s-fol1	50	68		99JU0562	s-fol1	47	69
99JU0527	sufol	88	38		99JU0562	s-fol1	11	44
99JU0528	s-fol1	232	70		99JU0562	sufol	122	78
99JU0528	s-bed	12	25		99JU0567	sufol	118	54
99JU0528	sufol	333	64		99JU0567	s-fol1	31	64
99JU0530	s-fol1	130	70		99JU0567	s-fol1	21	17
99JU0530	s-fol1	219	84		99JU0570	sufol	109	71
99JU0530	s-bed	274	33		99JU0577	sufol	144	20
99JU0530	sufol	274	33		99JU0577	s-fol1	5	62
99JU0530	s-fol1	122	59		99JU0577	sufol	138	18
99JU0532	s-bed	8	70		99JU0577	s-fol1	25	82
99JU0532	s-bed	279	62		99JU0577	s-fol1	344	89
99JU0532	sufol	279	62		99JU0578	s-fol1	6	71
99JU0532	s-fol1	113	85		99JU0581	sufol	108	30
99JU0532	s-fol1	183	83		99JU0585	ju	305	49
99JU0532	sufol	8	70		99JU0592	s-fol1	216	70
99JU0533	s-fol1	48	56		99JU0592	sufol	108	47
99JU0533	s-fol1	211	84		99JU0592	s-bed	108	47
99JU0533	sufol	311	75		99JU0592	s-fol1	5	79
99JU0533	s-bed	311	75		99JU0594	s-fol1	16	71
99JU0536	sufol	262	81		99JU0594	sufol	104	55
99JU0540	s-fol1	357	70		99JU0600	sufol	95	38
99JU0540	sufol	69	83		99JU0602	s-fol1	181	74
99JU0540	s-bed	69	83		99JU0602	s-fol1	215	59
99JU0540	s-fol2	105	90		99JU0602	sufol	95	28
99JU0541	sufol	1	65		99JU0602	sufol	95	28
99JU0541	sufol	268	78		99JU0602	s-fol1	215	59
99JU0545	sufol	60	23		99JU0602	s-fol1	181	74
99JU0549	s-fol1	111	17		99JU0603	sufol	60	39
99JU0549	sufol	121	88		99JU0605	sufol	91	31
99JU0549	s-fol1	210	90		99JU0605	s-fol1	239	39
99JU0550	sufol	110	88		99JU0605	sufol	109	36
99JU0551	sufol	151	68		99JU0605	s-fol1	131	71
99JU0552	sufol	125	84		99JU0608	sufol	54	20
99JU0553	sufol	109	77		99JU0608	s-fol1	241	56
99JU0554	sufol	110	52		99JU0609	sufol	58	40
99JU0554	s-fol1	356	58		99JU0630	s-fol1	19	31
99JU0554	ju	24	84		99JU0630	sufol	300	24
99JU0555	sufol	119	45		99JU0631	sufol	277	82
99JU0556	s-fol1	9	84		99JU0632	sufol	296	72
99JU0556	sufol	113	75		99JU0632	s-fol1	152	30
99JU0558	sufol	102	45		99JU0633	sufol	279	71
99JU0558	s-fol1	338	57		99JU0633	s-fol1	169	43
99JU0558	s-fol1	359	86		99JU0635	sufol	300	70
99JU0635	s-fol1	184	35		99JU0659	sufol	145	22

99JU0636	sufol	280	90		99JU0660	sufol	158	56
99JU0636	s-fol1	191	30		99JU0660	s-bed	279	62
99JU0637	sufol	256	55		99JU0661	s-bed	292	45
99JU0639	sufol	102	60		99JU0661	sufol	221	79
99JU0639	s-fol1	241	63		99JU0661	sufol	136	56
99JU0641	sufol	315	36		99JU0662	sufol	86	62
99JU0641	s-fol1	214	84		99JU0662	sufol	285	54
99JU0642	sufol	285	69		99JU0663	s-bed	86	62
99JU0642	s-fol1	148	58		99JU0663	sufol	86	62
99JU0645	s-bed	347	7		99JU0663	s-fol1	22	49
99JU0646	sufol	77	59		99JU0664	sufol	56	65
99JU0646	s-bed	301	34		99JU0664	s-bed	299	51
99JU0646	sufol	164	83		99JU0664	sufol	159	58
99JU0647	s-bed	5	25		99JU0666	sufol	292	82
99JU0647	sufol	322	89		99JU0666	s-fol2	161	33
99JU0647	sufol	74	85		99JU0666	s-fol1	29	52
99JU0648	sufol	29	54		99JU0669	sufol	334	77
99JU0648	sufol	335	86		99JU0670	sufol	319	69
99JU0648	s-bed	256	38		99JU0671	sufol	206	61
99JU0648	l-fold1	112	1		99JU0675	s-fol1	305	71
99JU0648	l-fold1	281	21		99JU0675	sufol	31	88
99JU0648	l-fold1	250	19		99JU0675	s-fol1	155	88
99JU0648	l-fold1	101	8		99JU0678	l-1	79	20
99JU0649	s-bed	261	65		99JU0678	s-fol1	57	64
99JU0650	s-fol1	235	62		99JU0678	s-fol1	139	79
99JU0650	s-fol1	131	90		99JU0678	sufol	59	37
99JU0650	sufol	336	52		99JU0678	l-1	87	23
99JU0650	s-fol1	69	88		99JU0678	s-fol1	159	88
99JU0650	s-bed	336	62		99JU0678	s-fol1	72	72
99JU0650	s-bed	9	48		99JU0678	s-bed	214	34
99JU0651	l-fold1	105	25		99JU0678	s-bed	38	45
99JU0651	l-fold1	114	23		99JU0678	sufol	23	49
99JU0651	l-fold1	104	22		99JU0678	s-fol1	158	72
99JU0651	l-fold1	89	24		99JU0678	s-fol1	252	71
99JU0652	sufol	280	80		99JU0678	sufol	48	40
99JU0653	s-fol1	28	90		99JU0679	s-bed	0	33
99JU0653	sufol	300	15		99JU0679	s-fol1	96	82
99JU0655	s-fol1	25	89		99JU0680	sufol	14	49
99JU0655	sufol	309	48		99JU0680	s-fol1	151	54
99JU0655	s-fol1	48	31		99JU0680	s-fol1	99	75
99JU0656	s-bed	331	39		99JU0681	sufol	13	44
99JU0656	sufol	223	75		99JU0681	s-fol1	165	69
99JU0657	s-bed	299	68		99JU0681	s-fol1	122	76
99JU0658	sufol	12	79		99JU0682	sufol	153	71
99JU0658	sufol	165	45		99JU0682	l-fold1	78	35
99JU0658	s-bed	275	84		99JU0682	l-fold1	87	28
99JU0659	s-bed	289	76		99JU0682	l-fold1	84	34
99JU0659	sufol	21	74		99JU0682	l-fold1	90	34
99JU0682	l-fold1	91	33		99JU0693	sufol	322	46

99JU0682	s-bed	38	42
99JU0683	s-bed	47	48
99JU0683	sufol	47	48
99JU0683	l-1	97	49
99JU0683	s-fol1	124	38
99JU0683	s-fol1	318	52
99JU0683	s-bed	23	45
99JU0683	sufol	23	45
99JU0683	l-1	92	45
99JU0683	s-fol1	168	42
99JU0684	s-bed	12	55
99JU0684	sufol	12	55
99JU0684	l-1	104	55
99JU0684	s-fol1	159	45
99JU0684	ju	105	74
99JU0685	sufol	31	50
99JU0685	s-fol1	172	50
99JU0685	s-fol2	85	67
99JU0685	ju	94	88
99JU0685	s-bed	46	45
99JU0685	l-1	107	41
99JU0685	s-bed	31	50
99JU0686	s-bed	2	36
99JU0686	sufol	14	41
99JU0686	l-1	93	40
99JU0686	sufol	155	62
99JU0687	s-bed	357	42
99JU0687	l-1	92	43
99JU0687	sufol	1	47
99JU0687	s-fol1	134	68
99JU0687	l-1	94	47
99JU0687	ju	209	67
99JU0688	s-bed	337	39
99JU0688	sufol	10	40
99JU0688	l-1	99	39
99JU0688	s-fol1	144	63
99JU0688	sufol	17	46
99JU0689	sufol	5	52
99JU0689	s-fol1	221	66
99JU0689	ju	201	73
99JU0689	ju	200	59
99JU0690	s-fol1	226	90
99JU0690	sufol	318	63
99JU0691	s-fol1	162	70
99JU0691	sufol	293	59
99JU0692	sufol	279	51
99JU0692	s-fol1	158	88
99JU0693	s-bed	226	90
99JU0694	s-fol1	87	49
99JU0694	sufol	344	51
99JU0694	s-bed	344	51
99JU0694	s-fol1	204	56
99JU0695	sufol	349	43
99JU0695	s-fol1	74	85
99JU0695	s-bed	349	43
99JU0695	s-fol1	154	45
99JU0696	s-bed	355	20
99JU0696	l-fold1	93	8
99JU0697	s-fol1	222	47
99JU0697	sufol	341	44
99JU0698	s-fol2	119	74
99JU0698	s-fol1	196	50
99JU0698	sufol	318	40
99JU0700	s-bed	324	54
99JU0700	s-bed	358	39
99JU0704	lu	93	10
99JU0704	sufol	299	13
99JU0704	sufol	211	66
99JU0705	sufol	305	14
99JU0706	sufol	333	33
99JU0706	s-fol1	205	54
99JU0707	sufol	356	26
99JU0707	s-fol1	175	72
99JU0709	s-bed	348	48
99JU0710	sufol	337	37
99JU0711	s-bed	326	38
99JU0711	s-fol1	210	80
99JU0711	s-fol2	150	63
99JU0712	sufol	334	18
99JU0712	s-bed	334	18
99JU0714	s-fol1	85	84
99JU0714	s-fol1	8	88
99JU0714	sufol	299	20
99JU0715	sufol	291	15
99JU0715	s-fol1	221	87
99JU0715	s-fol1	185	80

References

Armstrong, R.L 1988. Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera. Geological Society of America, Special Paper 218, pp. 55-92.

Armstrong, R.L., Parrish, R., Van Der Heyden, P., Scott, K., and Runkle, D. 1991. Early Proterozoic basement exposures in the southern Canadian Cordillera: core gneiss of Frenchman Cap, Unit I of the Grand Forks Gneiss, and Vaseaux Formation. Canadian Journal of Earth Sciences, **28**:1169-1201.

Bardoux, M. 1993. The Okanagan Valley Normal Fault from Penticton to Enderby, South-Central British Columbia. Ph.D. Thesis, Carleton University, Ottawa, Canada, 296p.

Bardoux, M., and Mareschal, J.C. 1994. Extension in south-central British Columbia: mechanical and thermal controls. Tectonophysics, **238**: 451-470.

Boghossian, N.D., Patchett, P.J., Ross, G.M., and Gehrels, G.E. 1996. Nd Isotopes and the Source of Sediments in the Miogeocline of the Canadian Cordillera. The Journal of Geology, **104**:259-277.

Brandon, A.D., Creaser, R.A., and Chacko, T. 1996. Constraints on Rates of Granitic Magma Transport from Epidote Dissolution Kinetics. Science, **271**:1845-1848.

Brown, R.L., and Read, P.B. 1983. Shuswap terrane of British Columbia: A Mesozoic "core complex". Geology, **11**:164-168.

Campbell, R.B., and Okulitch, A. V. 1973. Stratigraphy and structure of the Mount Ida Group, Vernon (82L), Adams Lake (82M W1/2), and Bonaparte Lake (92P) map-areas, British Columbia. *In* Report of Activities, April to October, 1972. Geological Survey of Canada, Paper 73-1, Part A, pp. 21-23.

Carter, E.S., Orchard, M.J., Ross, C.A., Ross, J.R.P., Smith, P.L., and Tipper, H.W. 1991. Part B: Paleontological signatures of the terranes. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse and C.J. Yorath. Geological Survey of Canada, no. 4, pp. 28-38. (also Geological Society of America, The Geology of North America, **G-2**)

Church, B.N., and Suesser, U. 1983. Geology and magnetostratigraphy of Miocene basalts of the Okanagan Highlands, British Columbia (82L/2, 3). *In* Geological Fieldwork 1983, Paper 1983-1, B.C. Geology Division, p. 32-36.

Coney, P.J., Jones, D.L., and Monger, J.W.H. 1980. Cordilleran suspect terranes. Nature, **288**:329-333.

Creaser, R.A., Erdmer, P., Stevens, R.A. and Grant, S.L. 1997. Tectonic affinity of Nisutlin and Anvil assemblage strata from the Teslin tectonic zone, northern Canadian Cordillera: Constraints from neodymium isotope and geochemical evidence. Tectonics, **16**(1):107-121.

Daly, R.A. 1915. A geological reconnaissance between Golden and Kamloops B.C., along the Canadian Pacific Railway. Geological Survey of Canada, Memoir 68, 260p.

Daughtry, K.L., Thompson, R.I., and Erdmer, P. 2000. New field studies of the Chapperon Group, Vernon southwest map area, British Columbia. *In* Current Research 2000-A19. Geological Survey of Canada, 4p. (online; http://www.nrcan.gc.ca/gsc/bookstore)

Dawson, G.M. 1898. Shuswap Sheet. Geological Survey of Canada, Map 604, scale 1:253 440.

Dostal, J., Church, B.N., Höy, T., 2001. Geological and geochemical evidence for variable magmatism and tectonics in the southern Canadian Cordillera: Paleozoic to Jurassic suites, Greenwood, southern British Columbia. Canadian Journal of Earth Sciences, **38**:75 - 90.

Erdmer, P., Heaman, L., Creaser, R.A., Thompson, R.I., and Daughtry, K.L. 2001. Eocambrian granite clasts in southern British Columbia shed light on Cordilleran hinterland crust. Canadian Journal of Earth Sciences, **38**:1007 - 1016.

Frebold, H., and Little, H.W. 1962. Paleontology, Stratigraphy, and Structure of the Jurassic Rocks in Salmo Map-area, British Columbia. Geological Survey of Canada, Bulletin 81.

Gabrielse, H. 1991. Structural Styles, Chapter 17. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse and C.J. Yorath. Ottawa, Geological Survey of Canada, no.4, pp. 571-675. (also Geological Society of America, The Geology of North America, **G-2**)

Gabrielse, H., Monger, J.W.H., Wheeler, J.O. and Yorath, C.J. 1991. Part A: Morphogeological belts, tectonic assemblages, and terranes, Chapter 2. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse and C.J. Yorath. Ottawa, Geological Survey of Canada, no.4, pp. 15-28. (also Geological Society of America, The Geology of North America, **G-2**)

Garzione, C.N., Patchett, P.J., Ross, G.M. and Nelson, J. 1997. Provenance of Paleozoic sedimentary rocks in the Canadian Cordilleran miogeocline: a Nd isotopic study. Canadian Journal of Earth Sciences, **34**:1603-1618.

Ghosh, D.K. 1995. Nd-Sr isotopic constraints on the interactions of the Intermontane Superterrane with the western edge of North America in the southern Canadian Cordillera. Canadian Journal of Earth Sciences, **32**:1740-1758.

Glombick, P., Erdmer, P., Thompson, R.I., and Daughtry, K.L. 2000. Geology of the Oyama map sheet, Vernon map area, British Columbia. *In* Current Research 2000-A14. Geological Survey of Canada, 10p. (online; http://www.nrcan.gc.ca/gsc/bookstore)

Goldstein, S.L., O'Nions, R.K., and Hamilton, P.J. 1984. A Sm-Nd isotopic study of atmospheric dusts and particulates from major river systems. Earth and Planetary Science Letters, **70**:221-236.

Harms, T.A. 1985. Pre-emplacement thrust faulting in the Sylvester Allochthon, northeast Cry Lake map area, British Columbia. *In* Current Research, Part A. Paper 85-1A, Geological Survey of Canada, pp. 301-304.

Heaman, L.M., Erdmer, P., and Owen, J.V. 2002. U-Pb Geochronologic Constraints on the Crustal Evolution of the Long Range Inlier, Newfoundland. Canadian Journal of Earth Sciences, in press.

Höy, T., and Andrew, K. 1991. Geology of the Rossland area, southeastern British Columbia (82F/4E). Geological Fieldwork 1990, Paper 1991-1, B.C. Ministry of Energy, Mines and Petroleum Resources, p. 21-31.

Höy, T., and Dunne, K.P.E. 1997. Early Jurassic Rossland Group, southern British Columbia. B.C. Ministry of Employment and Investment, Energy and Minerals Division, Geological Survey Branch, Bulletin 102, 124p.

Irving, E., Woodsworth, G.J., Wynne, P.J., and Morrison, A. 1985. Paleomagnetic evidence for displacement from the south of the Coast Plutonic Complex, British Columbia. Canadian Journal of Earth Sciences, **22**:584-598.

Irwin, W.P. 1972. Terranes of the western Paleozoic and Triassic belt in the southern Klamath mountains, California. U.S. Geological Survey, Professional Paper 800-C, pp. C103-C111.

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C., and Essling, A.M. 1971. Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U. Physics Review, **4**:1889-1906.

Johnson, B.J. 1990. Geology adjacent to the western margin of the Shuswap metamorphic complex (parts of 82 L, M). British Columbia Ministry of Energy, Mines, and Petroleum Resources, Open File 1990-30.

Johnson, B.J., 1994. Structure and tectonic setting of the Okanagan Valley fault system in the Shuswap Lake area, southern British Columbia. Ph.D. thesis, Carleton University, Ottawa, Canada, 266p.

Johnson, B.J., and Brown, R.L. 1996. Crustal structure and early Tertiary extensional tectonics of the Omineca belt at 51°N latitude, southern Canadian Cordillera. Canadian Journal of Earth Sciences, **33**:1596-1611.

Jones, A.G. 1959. Vernon Map-area British Columbia. Geological Survey of Canada, Memoir 296, 186p.

Klepacki, D.W. 1983. Stratigraphic and Structural Relations of the Milford, Kaslo, and Slocan Groups, Roseberry Quadrangle, Lardeau Map Area, British Columbia. *In* Current Research, Part A. Geological Survey of Canada, pp. 229-233.

Klepacki, D.W., and Wheeler, J.O. 1985. Stratigraphic and structural relations of the Milford, Kaslo, and Slocan groups, Goat Range, Lardeau and Nelson map areas, British Columbia. *In* Current Research, Part A. Geological Survey of Canada, pp. 277-286.

Ludwig, K.R. 1992. ISOPLOT – a plotting and regression program for radiogenic isotope data, version 2.57. U.S. Geological Survey, Open File Report 91, 445p.

McDonough, M.R. and Parrish, R.R. 1991. Proterozoic gneisses of the Malton Complex, near Valemount, British Columbia: U-Pb ages and Nd isotopic signatures. Canadian Journal of Earth Sciences, **28**(8):1202-1216.

Monger, J.W.H. 1977. Upper Paleozoic rocks of the western Canadian Cordillera and their bearing on Cordilleran Evolution. Canadian Journal of Earth Sciences, **14**:1832-1859.

Monger, J.W.H. 1985. Structural evolution of the southwestern Intermontane belt, Ashcroft and Hope map area, British Columbia. *In* Current Research, Part A. Geological Survey of Canada Paper 85 - 1A, pp. 349-358.

Monger, J.W.H. 1997. Plate tectonics and northern Cordilleran Geology: An unfinished revolution. Geoscience Canada, **24**:189:198.

Monger, J.W.H., Price, R.A., Tempelman-Kluit, D.J. 1982. Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera. Geology, **10**:70-75.

Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T., Struik, L.C., Campbell, R.B., Dodds, C.J., Gehrels, G.E., and O'Brian, J. 1991. Part B: Cordilleran terranes. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse, and C.J. Yorath. Geological Survey of Canada, no. 4, pp. 281-327. (also Geological Society of America, The Geology of North America, G-2)

Mortimer, N. 1986. Late Triassic, arc-related, potassic igneous rocks in the North American Cordillera. Geology, **14**:1035-1038.

Mortimer, N. 1987. The Nicola Group: Late Triassic and Early Jurassic subduction related volcanism in British Columbia. Canadian Journal of Earth Sciences, **4**:2521-2536.

Murphy, D.C., Walker, R.T., and Parrish, R.R. 1991. Age and geological setting of Gold Creek Gneiss, crystalline basement of the Windermere Supergroup, Cariboo Mountains, British Columbia. Canadian Journal of Earth Sciences, **28**(8):1217-1231.

Murphy, D.C., van der Heyden, P., Parrish, R.R., Klepacki, D.W., McMillan, W., Struik, L.C., and Gabites, J. 1995. New geochronological constraints on Jurassic deformation of the western edge of North America, southeastern Canadian Cordillera. Geological Society of America, Special Paper 299, pp. 159-167.

Okultich, A.V. 1979. Lithology, stratigraphy, structure and mineral occurrences of the Thompson-Shuswap-Okanagan area, British Columbia; Geological Survey of Canada Open File 637.

Okulitch, A.V. 1999. Geological time scale, 1999. Geological Survey of Canada, Open File 3040 (National Earth Science Series, Geological Atlas) – REVISION.

Parkinson, D. 1991. Age and isotopic character of Early Proterozoic basement gneisses in the southern Monashee Complex, southeastern British Columbia. Canadian Journal of Earth Sciences, **28**(8):1159-1168.

Parrish, R.R., and Monger, J.W.H. 1992. New dates from southwestern British Columbia. *In* Radiogenic age and isotopic studies: Report 5. Geological Survey of Canada, Paper 91-2, pp. 87-108.

Preto, V.A. 1972. Geology of Copper Mountain. British Columbia Department of Mines and Petroleum Resources, Bulletin 59, 87p.

Preto, V.A. 1977. The Nicola Group: Mesozoic volcanism related to rifting in southern British Columbia. *In* Volcanic Regimes in Canada. *Edited by* W.R.A. Baragar, L.C. Coleman, and J.M. Hall. The Geological Association of Canada, Special Paper No. 16, pp. 39-57.

Preto, V.A., Osatenko, M.J., Mc Millan, W.J., and Armstrong, R.L. 1979. Isotopic dates and strontium isotopic ratios for plutonic and volcanic rocks in the Quesnel Trough and Nicola Belt, south-central British Columbia. Canadian Journal of Earth Sciences, **16**:1658-1672.

Read, P.B., and Okulitch, A.V. 1977. The Triassic unconformity of south-central British Columbia. Canadian Journal of Earth Sciences, **14**:606-638.

Read, P.B., and Wheeler, J.O. 1976. Geology, Lardeau west half, British Columbia. Geological Survey of Canada Open-File Map 432, scale 1:125 000.

Rees, C.J., Irving, E., and Brown, R. L. 1985. Secondary magnetization of the Triassic-Jurassic volcaniclastic rocks of the Quesnel terrane, Quesnel Lake, B.C. Geophysical Research Letters, **12**(8):498-501.

Roback, R.C. and Walker, N.W. 1995. Provenance, detrital zircon U-Pb geochronometry, and tectonic significance of Permian to Lower Triassic sandstone in southeastern Quesnellia, British Columbia and Washington. Geological Society of America Bulletin, **107**(6):665-675.

Schau, M.P. 1970. Stratigraphy and structure of the type area of the Upper Triassic Nicola Group in south-central British Columbia. *In* Structure of the Southern Canadian Cordillera. *Edited by* J.O. Wheeler. Geological Association of Canada, Special Paper No. 6, p. 123-135.

Scholz, C.H. 1988. The brittle-plastic transition and the depth of seismic faulting. Geologische Rundschau, **77**:319-328.

Slemko, N.M. 2000. Structural, Metamorphic, and Plutonic History of Rock Adjacent to Shuswap Lake, British Columbia: Evidence of Early to Middle Paleozoic Deformation. Unpublished M.Sc. thesis, University of Alberta, Edmonton, Alberta, Canada. 174p.

Smith, A.D., Brandon, A.D., and Lambert, R.S. 1995. Nd-Sr isotope systematics of Nicola Group volcanic rocks, Quesnel terrane. Canadian Journal of Earth Sciences, **32**:437-446.

Souther, J.G., 1991. Volcanic regimes. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse, and C.J. Yorath. Geological Survey of Canada, no. 4, pp. 459-490. (also Geological Society of America, The Geology of North America, **G-2)**

Stacey, J.S., and Kramers, J.D. 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth and Planetary Science Letters, **26**:207-221.

Symons, D.T.A. 1983. New paleomagnetic data for the Triassic Guichon batholith of south-central British Columbia and their bearing on Terrane I tectonics. Canadian Journal of Earth Science, **20**:1340-1343.

Symons, D.T.A. 1985. Paleomagnetism of the Triassic Nicola volcanics and geotectonics of the Quesnellia subterrane of Terrane I, British Columbia. Journal of Geodynamics, **2**:229-244.

Tanaka, T., Togashi, S., Kamioka, H., Amakawa, H., Kagami, H., Hamamoto, T., Yuhara, M., Orihashi, Y., Yoneda, S., Shimizu, H., Kunimaru, T., Takahashi, K., Yanagi, T., Nakano, T., Fujimaki, K., Shinjo, R., Asahara, Y., Tanimizu, M., and Dragusanu, C. 2000. JNdi-1: a neodymium isotopic reference in consistency with La Jolla neodymium. Chemical Geology, **168**:279-281.

Taylor, D.G., Callomon, J.H., Hall, R., Smith, P.L., Tipper, H.W., and Westerman, G.E.G. 1984. Jurassic ammonite biogeography of western North America: The tectonic implications. *In* Jurassic-Cretaceous Biochronology and Paleogeography of North America. *Edited by* G.E.G. Westerman. Geological Association of Canada, Special Paper 27, pp. 121-141.

Taylor, S.R., and McLennan, S.M. 1985. The Continental Crust: its Composition and Evolution. Oxford, Blackwell Scientific Publications, 312p.

Tempelman-Kluit, D., and Parkinson, D. 1986. Extension across the Eocene Okanagan crustal shear in southern British Columbia. Geology, **14**:318-321.

Thompson, B., Mercier, E., and Roots, C. 1987. Extension and its influence on Canadian Cordilleran passive-margin evolution. *In* Continental Extensional Tectonics. *Edited by* M.P. Coward, J.F. Dewey and P.L. Hancock. Geological Society Special Publication No. 28, pp. 409-417.

Thompson, R.I., and Daughtry, K.L. 1996. New stratigraphic and tectonic interpretations, North Okanagan Valley, British Columbia. *In* Current Research 1996-A. Geological Survey of Canada, pp. 132-141.

Thompson, R.I., and Daughtry, K.L. 1997. Anatomy of the Neoproterozoic-Paleozoic continental margin, Vernon map-area, British Columbia. *In* Current Research 1997-A. Geological Survey of Canada, pp. 145-150.

Thompson, R.I., and Daughtry, K.L., 1998. Stratigraphic linkages across Vernon map area (82L), British Columbia. *In* Current Research 1998-A. Geological Survey of Canada, pp. 181-187.

Thompson, R.I., Glombick, P.M., Acton, S., Heaman, L.M., Friedman, R. Daughtry, K.L., Erdmer, P., and Paradis, S., 2002. New Constraints on the Age and Distribution of the Chase Quartzite, Vernon (82L) and Lardeau (82K) map areas: Regional Implications. *In* Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (February 21-24), Pacific Geoscience Centre. *Compiled by* F. Cook and P. Erdmer. Lithoprobe Report No. 82.

Unterschutz, J., Erdmer, P., Thompson, R.I., and Daughtry, K.L. 1999. Transition from Neoproterozoic to Triassic stratigraphy, Silver Star Mountain, Vernon map area, British Columbia. *In* Current Research 1999-A. Geological Survey of Canada, pp. 199-204.

Unterschutz, J.L.E., Creaser, R.A, Erdmer, P., Thompson, R.I., and Daughtry, K.L., 2002. North American margin origin of Quesnel terrane strata in the southern Canadian Cordillera: Inferences from geochemical and Nd isotopic characteristics of Triassic metasedimentary rocks. Geological Society of America Bulletin. (in press, April 2002)

Wheeler, J.O., and McFeely, P. 1991 (compilers). Tectonic Assemblage Map of the Canadian Cordillera and adjacent parts of the United States of America. Geological Survey of Canada, Map 1712A. 1:2 000 000 scale.

Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W., and Woodsworth, G.J. 1991 (compilers). Terrane Map of the Canadian Cordillera. Geological Survey of Canada, Map 1713A. 1:2 000 000 scale.

Wheeler, J.O., Campbell, R.B., Reesor, J.E., and Mountjoy, E.W. 1972. Structural style of the southern Canadian Cordillera. Guidebook, Excursion A-01 – X-01, XXIV International Geological Congress, Montreal, Quebec, 118p.

Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L. 1991. Plutonic regimes, Chapter 15. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse and C.J. Yorath. Geological Survey of Canada, no. 4, pp. 491-531. (also Geological Society of America, The Geology of North America, **G-2)**

Yorath, C.J. 1991. Upper Jurassic to Paleogene Assemblages, Chapter 9. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse and C.J. Yorath. Geological Survey of Canada, no. 4, pp. 331-371. (also Geological Society of America, The Geology of North America, **G-2)**

Chapter 3

North American margin origin of Quesnel terrane strata in the southern Canadian Cordillera: Inferences from geochemical and Nd isotopic characteristics of Triassic metasedimentary rocks

A version of this chapter has been accepted for publication in the Geological Society of America Bulletin, April 2002.

Introduction

The most inboard of the proposed accreted tectonic elements of the southeastern Canadian Cordillera, the Quesnel terrane (Quesnellia), has been described as a Triassic to early Jurassic intra-oceanic arc, formed in places atop Ordovician to Permian rocks of arc- and oceanic-affinity (Monger, 1977, 1985; Mortimer, 1986, 1987; Gabrielse et al., 1991; Monger et al., 1982, 1991, Souther, 1991; Dostal et al., 2001). Petrologic, geochemical and isotopic characteristics of metavolcanic rocks of the Upper Triassic Nicola Group, included as part of the Quesnel terrane, have been interpreted to reflect an arc setting with limited crustal contamination (Mortimer, 1986, 1987; Smith et al., 1995). Neodymium and Sr isotopic data from Late Triassic to Early Jurassic plutons intruding, and part of, the Quesnel terrane also show no clear evidence for extensive crustal contamination and have thus been interpreted to indicate that there was no continental crust beneath the Quesnel terrane at that time (Ghosh, 1995).

Current uncertainty regarding the basal contact of the Quesnel terrane exists because of conflicting interpretations regarding its relationship with underlying rocks. The Quesnel terrane is hypothesized to have been obducted onto rocks of the ancient North American margin between mid-Jurassic and Paleocene time, along a thrust fault with approximately 200 km of west-to-east displacement (e.g., Ghosh, 1995, and references therein). In southeast British Columbia, the Upper Triassic Nicola Group of the Quesnel terrane includes low-grade clastic metasedimentary strata that interfinger with volcanic rocks. These metasedimentary strata have been correlated with units to the east, also part of the Quesnel terrane, that are interpreted to unconformably overlie Paleozoic pericratonic rocks of the ancient margin (Jones, 1959; Read and Okulitch, 1977; Klepacki, 1983; Klepacki and Wheeler, 1985; Höy and Andrew, 1991; Roback and

Walker, 1995; Thompson and Daughtry, 1996, 1997, 1998; and Unterschutz et al., 1999a). Observation of this contact west of Lower Arrow Lake (Fig. 3-1) is complicated by the paucity of outcrop. In addition, there are metamorphic clasts, including Proterozoic granite (555.6 ± 2.5 Ma, U-Pb zircon), in metaconglomerate of undetermined age beneath what appears to be a thin veneer of Quesnel terrane strata, 30 km northwest of Vernon (see Fig. 3-1) (Erdmer et al., 2001a). This metaconglomerate has been interpreted to represent a continuation of pericratonic rocks across the Okanagan Valley (Erdmer et al., 2001a) into an area where the Quesnel terrane was thought to be 24 to 30 km thick (e.g. Cook et al., 1992; Varsek and Cook, 1994). Approximately 100 km west of Vernon in the Nicola horst, an area of high-grade metamorphic rocks surrounded by low-grade strata of the Quesnel terrane, an igneous clast in metaconglomerate is ~1.04 Ga (U-Pb zircon, Erdmer et al., 2001b). This has been interpreted to indicate that Proterozoic crust was at the surface at the time of deposition of these rocks, and further supports the hypothesis that the lithosphere in this area is not simply a thick crustal slice of the Quesnel terrane (Erdmer et al., 2001b).

An unconformable contact between rocks of the Quesnel terrane in southeastern British Columbia and rocks tied to the North American craton would preclude any significant displacement of the Quesnel arc with respect to the margin since the late Triassic. This would also preclude its status as an allochthon or, alternatively, suggests that some rocks in southeastern British Columbia are incorrectly assigned to the Quesnel terrane. This study examines the possibility that the Quesnel terrane is pericratonic by examining the provenance characteristics of sedimentary rocks deposited contemporaneously with Quesnel arc development, and prior to the proposed obduction onto the continental margin.

Clastic sedimentary rocks are widely used as indicators of sedimentary provenance because sedimentary basins reflect the nature of their source areas (e.g., Bhatia and Crook, 1986; Nelson and DePaolo, 1988; Frost and Coombs, 1989; McLennan and Taylor, 1991; McLennan and Hemming, 1992; McLennan et al., 1993, 1995; and references therein). Elements such as Th, Sc, Cr, Co and the rare earth elements (REE, including Sm and Nd) are effective provenance tracers because of their low concentrations in river- and sea-water, their low oceanic residence times, and

because they have been shown to be immobile during geological processes such as weathering, diagenesis and low-grade metamorphism (Taylor and McLennan, 1985, and references therein). These elements "see through" the effects of low-grade metamorphism (e.g. Feng et al., 1992; Creaser et al., 1997). This study is seeded in previous work, in which three samples of clastic sedimentary rocks from Triassic strata in the Quesnel terrane were analyzed for Nd isotopic compositions, and which revealed the presence of continental detritus in the sedimentary record (Ghosh and Lambert, 1989; Patchett and Gehrels, 1998). This paper presents Nd isotopic and geochemical data from 24 clastic metasedimentary rocks along a ~ 300 km transect of the Quesnel terrane in southeastern British Columbia, in attempt to track the abundance, distribution, and lithological controls of this continental signature, to assess whether the source of evolved continental material was proximal to the depositional basin, and to determine the likelihood that this source was North American.

The term 'evolved' is used to refer to rocks with geochemical and Nd isotopic characteristics compatible with the old upper continental crust (OUC) provenance type defined by McLennan et al. (1993), which describes rocks that have undergone intracrustal melting processes and have εNd_0 values $\leq$ -10 and Eu/Eu* values ~0.60-0.70. The term 'primitive' is used to refer to rocks with geochemical characteristics compatible with the young undifferentiated arc (YUA) provenance type of McLennan et al. (1993), which represents young, mantle derived volcanic and plutonic rocks from arcs that have not undergone intracrustal differentiation processes and have εNd_0 values +5 and Eu/Eu* values ~ 1.0. The geochemical and Nd isotopic data reported here confirm that the volcanic component of the Quesnel arc, represented by Nicola Group volcanic rocks, was not the only source of detritus for intercalated clastic strata, and indicate that detritus was also derived from an evolved continental source. The similarity of the evolved Nd isotope and geochemical data to rocks from the North American miogeocline suggests that North America and the Quesnel arc are the most likely sources of detritus within the Triassic clastic succession of the Quesnel terrane in southeastern British Columbia. This interpretation implies a parautochthonous or distal continental margin origin for the Quesnel arc, which, in turn, implies that the Quesnel terrane in the southeastern Canadian Cordillera is not exotic.

Geologic Framework

The Paleozoic basement of the Quesnel terrane is poorly known, but has been divided into the Harper Ranch subterrane, a sequence of arc-related clastic, volcaniclastic, and volcanic rocks and podiform carbonates, and the Okanagan subterrane, which includes limestone, chert, argillite, basalt and ultramafic rocks (Read and Okulitch, 1977; Monger, 1977; Monger et al. 1991). The Quesnel arc assemblage within the study area (Fig. 3-1) sits, in places, upon this Paleozoic basement and consists of low-grade metamorphosed sedimentary, volcaniclastic, and volcanic rocks of the Slocan, Ymir, and Nicola groups (Fig. 3-2) (Jones, 1959; Little, 1960; Schau, 1968, 1970; Preto, 1977; Read and Okulitch, 1977; Souther, 1977; Klepacki, 1983; Klepacki and Wheeler, 1985; Höy and Andrew, 1988; Monger et al., 1991; and references therein). In south-central British Columbia, the Nicola Group has been divided into three belts (Preto, 1977; Preto et al., 1979; Monger, 1985; Monger et al., 1982, 1991). The western belt consists of Upper Carnian to Lower Norian felsic, intermediate and more rarely mafic volcaniclastic rocks, and includes local ignimbrite, minor carbonate, and pelite. These rocks interfinger structurally and depositionally with the more outboard Cache Creek terrane (Travers, 1977). The central belt is characterized by a transition to intermediate volcanic and volcaniclastic rocks - mainly feldspar and feldspar-augite porphyry - with local carbonate and volcanic sandstone of early Norian age, overlain by pillow basalt, augite porphyry, volcaniclastic rocks, and alkaline flows of late Norian age. The eastern belt is broadly similar to the central belt, but includes a greater proportion of volcaniclastic rocks (Preto, 1977; Preto et al., 1979). The three belts are structurally juxtaposed in some areas (Preto et al., 1979; Monger, 1985), while grading depositionally into one another in other areas (Schau, 1968; Mortimer, 1987; and references therein). A lateral facies transition has been recorded eastward into a sedimentary facies, the temporal and lithological correlative of the Slocan and Ymir groups (Fig. 3-2) (Mortimer, 1987; Monger et al., 1991; Thompson and Daughtry, 1998), which consists of argillite, slate and metasiltstone with local lenses of volcaniclastic rocks, limestone and breccia.

On the basis of macro- and microfossils in sedimentary rocks of the Nicola and Slocan groups, the time span of deposition of the studied Triassic strata ranges from 227 to 210 Ma (Okulitch and Cameron, 1976; Travers, 1977; Preto, 1979; Orchard, 1985;

Read, 1996; Thompson and Daughtry, 1996). This time span is supported by absolute age determinations. An Rb-Sr isochron of 222 ± 15 Ma was obtained from a high- to low-potassium basalt to rhyolite suite of the Nicola Group (Smith et al. 1995). A tuff in the western belt of the Nicola Group has been dated at 222.5 ± 1.4 Ma (U-Pb zircon, Moore et al., 2000). A minimum age of the Nicola Group is provided by the crosscutting Guichon batholith (210 ± 3 Ma , U-Pb zircon, Mortimer et al. 1989).

Previous Nd Isotope and Geochemical Studies

Mortimer (1987) used major and trace element data from volcanic rocks of the Nicola Group, together with the presence of reefoid limestones and extrusive rocks of silicic to intermediate composition and the absence of pillow basalt and ophiolite, to refute early interpretations that the Nicola Group formed at a mid-oceanic ridge in a rift setting (Hollister, 1976; Preto, 1977; Souther, 1977). Mortimer (1987) further inferred that the magmas represented by the volcanic rocks had geochemical characteristics of island-arc and intraplate tectonic settings (Mortimer, 1987). This proposal is supported by εNd_T values ranging from +5.0 to +7.9, consistent with values expected in early Mesozoic island arcs (Smith et al., 1995). Geochemical and Nd isotope studies on the Paleozoic Harper Ranch and Okanagan subterranes within the Quesnel terrane reveal positive εNd_T values (+2.9 to +11.6), and La_N/Yb_N ratios between 0.4 and 4 (Ghosh, 1995; Patchett and Gehrels, 1998; Dostal et al., 2001). In the Greenwood area, middle Triassic rocks of the Brooklyn Group also have geochemical (La_N/Yb_N ratios between 2.5 and 4.5) and Nd isotope values (εNd_{230} values between +5.5 and +8.4) consistent with an island-arc setting (Dostal et al., 2001).

Previous isotopic analysis of sedimentary strata from the Nicola, Slocan and Ymir groups revealed εNd_T values ranging from –5 to –12 (Ghosh and Lambert, 1989; Patchett and Gehrels, 1998; Unterschutz et al., 1999b). These values contrast strongly with the positive εNd_T values of contemporaneous volcanic facies in the Nicola Group (Smith et al., 1995). Negative εNd_T values are not typical of intra-oceanic arcs, rather, they reflect a contribution from evolved continental crust to the arc setting.

Patchett and Gehrels (1998) suggested that negative εNd_T values of sedimentary rocks from the Quesnel and Cache Creek terranes, which are consistent with results from the North American miogeocline (Jackson, 1992; Boghossian et al., 1996; Garzione et al., 1997), could indicate proximity to ancestral North America. They placed constraints on this proximity by suggesting that if North America was the source of this continental detritus via water-borne transport, the oceanic Cache Creek terrane, tied to the western margin of the Quesnel terrane, was at a maximum distance of between 1,500 and 3,000 km from the continent during its development (Patchett and Gehrels, 1998). Further constraints on the location of these terranes are provided by Nd isotopic compositions of Triassic miogeoclinal strata in northern British Columbia and southwestern Alberta (Jackson, 1992; Boghossian et al., 1996), which are consistently evolved ($\varepsilon Nd_{220} = -6.8$ to -10.7). This failure to demonstrate a contribution to the miogeocline from the Quesnel arc may provide a limit to the eastern extent of significant sediment influx from the arc, and thus help define its position relative to the North American margin in Triassic time.

Sampling Method and Analytical Technique

Twenty-four samples of metasedimentary rocks from the Slocan, Ymir, and Nicola groups of southeastern British Columbia, ranging in grain size from clay- to sand- and in metamorphic grade from greenschist to amphibolite, were analyzed for their major, trace element, and Sm-Nd isotopic composition and concentrations (Tables 3-1, 3-2, 3-3; Fig. 3-1). Although these three groups are considered correlative (e.g. Monger et al., 1991, and references therein), a definitive link between Nicola Group rocks and those of the Slocan and Ymir groups has yet to be documented. The present study attempts to address this concern by examining sedimentary strata from all three groups. Sample RC 99-14 comes from the eastern belt and samples RC 99-15, RC 99-16, and RC 99-17 come from the sedimentary facies belt of the Nicola Group as defined by Monger (1985, and references therein). The remaining samples come from the sedimentary-dominated successions of the Slocan and Ymir groups, or rocks correlated to these groups or the sedimentary facies of the Nicola Group. Samples analyzed showed minor or no surface alteration and were not collected near crosscutting veins or intrusions that may have

altered the bulk chemistry. The sampling of a range in sediment grain size from clay to sand allowed an assessment of whether grain size controls the Nd isotopic composition (Table 3-2). All samples were examined in thin section to determine primary grain size and mineralogy.

Samples were ground to < 30 μm powder, and major and trace element concentrations determined at Washington State University using XRF (x-ray fluorescence) and ICP-MS (inductively coupled plasma mass spectrometry) techniques outlined by Johnson et al. (1999) and Knaack et al. (1994), respectively. Sm-Nd isotopic analyses were conducted at the Radiogenic Isotope Facility at the University of Alberta using isotope dilution mass spectrometry (e.g., Creaser et al., 1997). Over the period of analyses presented here, the $^{143}Nd/^{144}Nd$ value determined for the Shin Etsu Nd standard was 0.512097 ± 13 (1SD, n = 34), in agreement with previous determinations for the standard by Tanaka et al. (2000). Data were corrected to a $^{143}Nd/^{144}Nd$ value of 0.512107 for Shin Etsu, which is equivalent to 0.511850 for the La Jolla standard (Tanaka et al. 2000). Chemical processing blanks were < 400 pg for Nd and Sm.

Results

Petrography

Clastic metasedimentary rocks used in this study are composed of particles varying between clay- and sand-size. These rocks vary in metamorphic grade from chlorite- to biotite-grade with the exception of two samples, which are garnet-grade (PE 99-40 and PE 99-24; Table 3-2). Samples were examined in thin section to evaluate detrital grain size and mineralogy. Determining primary mineralogy is complicated by the presence of up to 40% fine-grained opaque material in many samples, most likely graphite, and by the subsequent growth of metamorphic minerals, particularly biotite and chlorite. Most samples contain some percentage of very fine-grained material that cannot be identified in thin section; samples PE 99-40, PG 99-691, RC 99-2, RC 99-9, RC 99-14, and RC 99-17 are too fine-grained to discern the primary mineralogy. Some general observations can be made from the samples in which the primary mineralogy could be observed. Samples are divided into two groups, based on clearly differing quartz and plagioclase contents (Table 3-2). The quartz-rich group includes rocks with modal

compositions of greater than 40% quartz and between 0 to 10% plagioclase; the quartz-poor group samples have modal compositions of less than 30% quartz and up to 40% plagioclase. These two groups cannot be differentiated in hand sample.

Major Element Chemistry

Major element abundances are used to provide a general lithological classification of the studied rocks (Table 3-1). SiO_2 contents vary between 48 and 89 wt. % and Al_2O_3 contents between 5 and 21 wt. %. Chemical classification of the sediments using $\log(SiO_2/Al_2O_3)$ vs. $\log(Na_2O/K_2O)$ (Pettijohn et al., 1987) defines the analyzed samples as greywacke (n = 14), lithic arenite (n = 9), and arkose (n = 1) (Fig. 3-3). Because of the known mobility of major elements during processes such as weathering and metamorphism (cf: Taylor and McLennan, 1985, and references therein), further analysis of these elements was not pursued.

Trace Element Chemistry

The analyzed samples show a broad range of trace element compositions (Table 3-1). They are enriched in the light rare earth elements (LREE) (Fig. 3-4), with La_N/Yb_N ratios between 3.85 and 11.40; La/Sc ratios range between 0.38 and 4.76, and Th/Sc ratios vary between 0.09 and 1.62 (Table 3-1; Fig. 3-5a,b,c). When compared with Nicola Group volcanic rocks and clastic sedimentary rocks of the North American miogeocline, the values for the Triassic metasedimentary rocks overlap both and form a roughly linear trend between the two (Fig. 3-5a,b,c). This variation in enrichment is also reflected in Eu/Eu* values that range between 0.6 and 1.0 (Table 3-1; Fig. 3-4); the lack of an Eu anomaly generally indicates the presence of first-cycle volcanogenic sediments (Taylor and McLennan, 1985). Using the elements La, Th, Sc, and Zr, tectonic discrimination diagrams for graywacke (Bhatia and Crook, 1986) allow distinction between oceanic island arc, continental island arc, active continental margin and passive margin environments of deposition. Samples in this study form an array between fields of high Sc – low Th, Zr, La and low Sc – high Th, Zr, La (Fig. 6). Volcanic rocks of the Nicola Group plot within the high Sc – low Th, Zr, La areas of the diagrams (Fig. 3-6). No geochemical data from Triassic sedimentary rocks of the North American

miogeocline are available; Devonian miogeoclinal strata, the closest in age for which data are available, plot within the low Sc – high Th, Zr, La fields (Fig. 3-6).

Nd Isotopic Data

Sm-Nd isotopic abundances provide information on the source of detritus in clastic sedimentary rocks (e.g. Goldstein et al., 1984). Nd isotopic data are reported in epsilon units (εNd) and using depleted mantle model ages (T_{CR}; Goldstein et al., 1984). For the purpose of calculation, a depositional age of 220 Ma is assumed.

The Triassic metasedimentary rocks show a large range in εNd_{220} values, from –10 to +5.5 (Table 3-1). The relationship between εNd_{220} values and trace element abundance in the metasedimentary rocks is illustrated in Figure 5 (d,e), where εNd_{220} values are plotted against La/Sc and Th/Sc ratios. In general, samples with more positive εNd_T values show lower Th/Sc and La/Sc ratios. The data define a broadly linear trend between contrasting values for Nicola Group volcanic rocks and clastic sedimentary rocks of the North American miogeocline (Fig 5d,e, Fig. 3-7). Calculated Nd model ages for the samples show a large variation from 0.63 to 2.27 Ga, indicating contributions of clastic influx from rocks having at least two different average crustal residence ages (Table 3-2).

To investigate the extent of influence of nearby volcanic rocks on the composition of sedimentary rocks, rocks both adjacent to and remote from interlayered volcanic units were sampled. Samples RC99-10 and RC99-11 were collected from the lowest exposed part of the Ymir Group, where no volcanic rocks are known locally, and yielded εNd_{220} values of -6.9 and –8.5, respectively. Samples RC99-9 and RC99-12 were collected from the upper part of the Ymir Group, near the contact with overlying volcanic rocks of the Elise Formation, and yielded εNd_{220} values of +3.5 and +4.0. The clear influence of local volcanic sources on sediment composition is also shown by the correlation of data from petrographic analysis with εNd_{220} values. Quartz-poor samples are characterized by positive εNd_{220} values (Table 3-2) and contain a high proportion of plagioclase, indicating that they are less mature sediments. This is further supported by the lack of a Eu anomaly in quartz-poor samples RC 99-12, RC 99-16, and PE 99-44 (Table 3-1), a geochemical characteristic considered indicative of first cycle volcanogenic detritus

(Taylor and McLennan, 1985). Quartz-rich samples show negative εNd_{220} values (Table 3-2) and contain very little plagioclase, suggesting they are more mature sediments. Quartz-rich samples each possess a negative Eu anomaly (Table 3-1), a geochemical characteristic considered indicative of rocks having undergone intracrustal differentiation processes, in this case indicating that characteristic in the source rocks for the Triassic metasedimentary rocks (Taylor and McLennan, 1985).

Geochemical characteristics can be related to the grain size of rocks analyzed. For example, Jackson (1992) found that within the Cache Creek terrane of northern British Columbia and the Yukon, fine-grained clastic rocks yield generally more negative εNd_T values and older model ages than coarser grained samples. While the relationship was not without exception (for example, one sample of argillite yielded an εNd_{200} value of +6, more positive than the corresponding sandstone), the results imply that evolved continentally derived detritus may travel long distances in fine-grained sediment fractions and influence the isotopic composition of rocks quite distant from the source. However, in this study, no correlation between grain size and εNd_{220} value was found, with rocks of all grain sizes showing variable εNd_{220} values (Table 3-2, Fig. 3-8). There also is no east-west or north-south trend in the data, i.e., rocks did not display a clear evolution or break from evolved to primitive characteristics in relation to geographic position (Fig. 3-9).

Discussion and Implications

Sediment Source

The large variations in εNd_{220} values and Nd model ages of the Triassic metasedimentary rocks of the Quesnel terrane in southeastern British Columbia show that the Quesnel volcanic rocks could not have been the only source of detritus for the intercalated sedimentary strata (Fig. 3-7). A similar spread is seen in trace element abundances that vary between high Sc – low Th, Zr, La sources such as mafic volcanic rocks, and low Sc – high Th, Zr, La sources such as felsic continental crust (Fig. 3-6) (cf: Creaser et al., 1997). The Bhatia and Crook (1986) plot (Fig. 3-6) was not used to infer a tectonic setting of deposition, rather, it was used to differentiate between geochemically variable source rocks. All geochemical and isotopic data are consistent with a mixed

provenance from sources with distinctly different chemical characteristics, which include a primitive source and an evolved continental source.

A North American Source?

Volcanic rocks of the Nicola Group possess Nd isotopic and geochemical characteristics consistent with a primitive arc origin (Mortimer, 1987; Smith et al., 1995), and are the most obvious proximal source with a primitive composition for the Triassic metasedimentary rocks examined here. The nature of the evolved source is more speculative, but comparison of our data with values from the North American miogeocline shows that the compositions of the more evolved samples are similar to those of the miogeoclinal strata (Figs. 3-5, 3-7). The geochemical and Nd isotopic data presented here typically form a rough linear trend intermediate between, and overlapping, data from the miogeocline and Nicola Group volcanic rocks. Input of detritus from a North American source into the Quesnel terrane is also supported by a provenance study of sedimentary rocks from the Paleozoic Harper Ranch assemblage of the Quesnel terrane, in places the basement to the Triassic strata, which also shows the North American craton to be a source of detritus (Roback and Walker, 1995).

The regional Nd isotopic study of Patchett and Gehrels (1998) on inboard terranes within the Canadian Cordillera allowed them to speculate that the source of evolved continental detritus in these terranes could be North American, but left the question of the proximity of these terranes to North America unresolved. Our data show the abundant, widespread, and consistent presence of evolved continental material within the Upper Triassic sedimentary record of the Quesnel terrane. Without the ability to distinguish evolved from primitive samples in the field, 16 out of 24 samples in this study show negative εNd_{220} values. From this, it is reasonable to estimate that at least 50% of all sedimentary rocks within the Quesnel terrane of southern British Columbia show evidence for continental affinity. This abundance, along with a lack of correlation between εNd values and grain size or geographic location, can be interpreted to record proximity of the continental source to the Triassic depositional basin. The similarity of this evolved signature to more inboard strata of the North American miogeocline, combined with the geological evidence of a stratigraphic tie of Quesnel terrane strata to

rocks of, or tied to, North America, strongly suggests that North America was the source of the evolved detritus.

Other Possibilities

An alternative interpretation, proposed by Ghosh and Lambert (1989), is that a block of continental crust to the west of a Quesnel intra-oceanic arc, having an Nd model age of ~1.9 Ga, contributed the evolved material. That hypothesis could be compatible with the notion of an alpine rift system for the Cordillera as proposed by Struik (1987), in which parts of the North American craton rifted during extension between late Proterozoic and Devonian time, and which, if exposed, may have been a source of detritus for surrounding sedimentary basins. However, such a block has not been observed, and it should be noted that the interpretation of Ghosh and Lambert (1989) was made prior to the availability of any Nd isotopic data from rocks of the North American miogeocline. Limited Nd data are available from Cache Creek terrane rocks outboard of the Quesnel terrane; in Cache Creek clastic sedimentary rocks have generally primitive εNd_T values and coarse-grained rocks are largely primitive (Jackson, 1992; Patchett and Gehrels, 1998). This suggests that local sources west of the Quesnel terrane did not have an evolved continental nature. Further study on sedimentary rocks from the Cache Creek and other outboard terranes is needed to substantiate this suggestion.

Implications

Quesnel Terrane

The data enable conclusions to be drawn about the broad Nd isotopic characteristics of the Quesnel terrane in southeastern British Columbia. Metasedimentary rocks of the Nicola, Slocan and Ymir groups all show a range of evolved and primitive εNd_{220} values; this supports their previously proposed correlation. Our data also show a significant difference in Nd isotopic characteristics between the sedimentary and volcanic facies of Triassic rocks of the Quesnel terrane. All of the geological and Nd isotopic data now available (this study; Smith et al., 1995; Ghosh, 1995) show a prevalence of sedimentary rocks with evolved Nd isotopic values in the east, contrasting with a dominance of volcanic rocks with primitive Nd isotopic values in the west. Thus, the

overall Nd isotopic character of supracrustal rocks in the Quesnel terrane in southeastern British Columbia is more evolved in the east and more primitive in the west. This should be taken into account when considering the potential contamination that local rocks could contribute to intrusive igneous bodies (e.g., Ghosh, 1995).

Tectonic Setting

The tectonic setting of the Quesnel terrane has been widely described as that of a Triassic to early Jurassic intra-oceanic arc, which was accreted to the North American continental margin starting in mid-Jurassic time (e.g., Ghosh, 1995; Monger et al., 1982, 1991). However, the evolved Nd isotopic and geochemical features of Triassic metasedimentary rocks of all grain sizes from the Quesnel terrane in southeastern British Columbia are inconsistent with sediment deposition as part of an intra-oceanic arc. Similarly inconsistent are the recent discoveries of older supracrustal successions beneath apparently thin veneers of Triassic rocks of the Quesnel terrane in southeastern British Columbia (Erdmer et al. 2001a, 2001b). Those pre-Triassic strata have been interpreted to be pericratonic in origin, and contain U-Pb and Nd isotope evidence of derivation, at least in part, from a Precambrian source region.

Instead, the interpretation that the Quesnel arc, and other rocks currently assigned to the Quesnel terrane, formed as a continental margin assemblage on ancestral North America is offered, where a Triassic back-arc depositional basin received sediment input from both a primitive magmatic arc and the continent. This interpretation differs from that presented by Ghosh (1995), which was based upon Nd and Sr isotope data from igneous bodies that have intruded the Quesnel terrane in southern British Columbia, and form part of it.

On the basis of their primitive εNd_T and initial $^{87}Sr/^{86}Sr$ values (hereafter Sr_T), Triassic and early Jurassic igneous rocks of the Quesnel terrane (215-190 Ma) were interpreted by Ghosh (1995) to have been emplaced into Paleozoic oceanic crust outboard of North America. Ghosh (1995) interpreted a shift from these primitive εNd_T and Sr_T values to more evolved εNd_T and Sr_T values in mid-Jurassic and younger igneous rocks (<180Ma), to reflect the onset of crustal contamination caused by progressive obduction of the Quesnel terrane onto the continental margin starting in mid-Jurassic time. The

crustal contamination observed by Ghosh (1995) in post mid-Jurassic igneous rocks indeed increases from west to east, manifest as a strong eastward decrease in εNd_T and increase in Sr_T. One line of evidence called upon as supportive of an intra-oceanic origin for the Quesnel arc is the appearance of strongly evolved εNd_T values in mid-Jurassic time, and the absence of such values in Triassic to early Jurassic time.

Several points relating to the study of Ghosh (1995) require discussion. The strongly evolved εNd_T values in mid-Jurassic igneous rocks are evident only east of longitude 119-120°W, comprising 23 igneous rock analyses with negative εNd_T values. By comparison, an early Jurassic hornblende andesite from the Rossland Group was the only sample of Triassic to early Jurassic igneous rocks analyzed by Ghosh (1995) east of longitude 119°W (Fig. 3-10a). All remaining Quesnel terrane samples of Ghosh (1995) east of longitude 119°W are Paleozoic samples from a Quesnel terrane basement assemblage or from a separate terrane, including a massive volcanic rock from the Kaslo Group, which has been interpreted as part of the Slide Mountain terrane, and greenschist, greenstone and amphibolite from rocks part of, or correlated to, the Harper Ranch assemblage. Thus, the interpreted shift from primitive to evolved isotopic signatures in igneous rocks in mid-Jurassic time rests entirely on one pre mid-Jurassic datum. Substantially more pre–middle Jurassic isotopic data from east of 119°W are required to verify the notion of an isotopic shift.

Furthermore, late Triassic to early Jurassic granitoid plutons of the Quesnel terrane have εNd_T values comparable with rocks of mid- to late Jurassic age and younger at the same longitude (Fig. 3-10; see Ghosh 1995). It is also apparent that a small but clear decrease in εNd_T from west of 121°W to 119-120°W exists in these Triassic to early Jurassic plutons (Fig. 3-10a), just as in mid-Jurassic and younger igneous rocks at the same longitude (Figs. 3-10b-d). The sole outlier in a general pattern of decreasing εNd_T from west to east in 85 Mesozoic rocks of the Quesnel terrane analyzed by Ghosh (1995) remains the single hornblende andesite from the Rossland Group.

Thus, a pattern of eastwardly more evolved isotopic signatures in igneous rocks of the Quesnel terrane has been a characteristic feature since Triassic time. Such a pattern

does not require obduction of an exotic oceanic terrane, but could equally result from the development of the Quesnel arc on an eastwardly thickening wedge of continentally derived material. This is consistent with formation of the Quesnel terrane on or near the edge of the North American passive margin, as required by the isotopic data for Triassic metasedimentary rocks presented here. Any pattern of eastwardly increasing contamination in igneous rocks could have been amplified by contamination from Triassic supracrustal rocks, which are demonstrably intruded. The latter are dominated by isotopically evolved metasedimentary rocks in the east, and by isotopically primitive volcanic rocks in the west.

Conclusions

Nd isotopic and trace element geochemical compositions of Triassic clastic metasedimentary rocks of the Quesnel terrane in southeastern British Columbia show a mixed provenance between a primitive arc and evolved continental crust. The widespread occurrence of clastic sedimentary rocks of a range of grain sizes with evolved compositions within the Quesnel terrane does not support its development as an intra-oceanic arc. These more evolved metasedimentary rocks show Nd isotopic compositions that are indistinguishable from contemporaneous clastic sedimentary rocks of the North American miogeocline. The abundant, consistent and widespread continental signature within Triassic sedimentary rocks of the Quesnel terrane can be interpreted to indicate that the arc was proximal to North America throughout its development. These new data, coupled with geological data describing unconformable relationships between Quesnel terrane rocks and strata tied to or of North American origin, lead to the conclusion that the Quesnel terrane in southeastern British Columbia formed as an arc assemblage on or near the ancient North American margin in late Triassic time.

TABLE 3-1. MAJOR AND TRACE ELEMENT CONCENTRATIONS AND CALCULATED RATIOS

sample	RC99 1	RC99 2	RC99 3	RC99 4	RC99 5	RC99 6	RC99 7	RC99 8	RC99 9	RC99 10	RC99 11	RC99 12
Major elements (wt. %)												
SiO_2	51.87	64.16	75.52	86.51	74.34	65.07	70.25	74.83	58.51	69.08	72.04	59.73
Al_2O_3	17.08	19.97	6.88	5.20	7.10	18.52	13.38	11.52	16.68	13.77	13.26	17.81
TiO_2	0.918	0.842	0.342	0.260	0.348	0.892	0.654	0.702	0.792	0.670	0.739	0.676
FeO	10.10	4.57	1.36	2.01	2.54	6.64	4.17	3.32	6.95	4.37	3.26	7.04
MnO	0.168	0.021	0.055	0.041	0.093	0.084	0.122	0.112	0.136	0.071	0.032	0.101
CaO	8.18	0.56	9.86	2.99	10.65	0.85	3.38	3.31	8.40	3.80	2.91	4.75
MgO	4.86	1.58	2.21	0.35	1.51	2.83	4.34	1.83	3.57	3.83	2.52	3.25
K_2O	3.04	3.51	0.64	0.53	1.50	3.47	2.66	2.34	1.32	2.77	2.38	2.56
Na_2O	3.42	4.41	2.93	2.06	1.73	1.48	0.91	1.87	3.34	1.51	2.73	3.73
P_2O_5	0.365	0.375	0.190	0.066	0.178	0.172	0.139	0.157	0.285	0.134	0.127	0.349
Trace elements (ppm)												
Ba	1153	1521	135	202	743	671	831	509	769	354	493	1231
Rb	70.72	69.91	18.75	23.75	42.67	150.28	92.65	93.86	34.73	131.17	97.71	66.50
Cs	4.25	3.77	0.83	1.08	2.69	7.31	4.00	5.00	1.41	10.26	7.43	3.34
Sr	602	304	289	57	380	158	174	143	546	155	205	809
Pb	8.6	9.5	7.6	9.3	4.7	17.9	10.4	23.9	6.3	9.9	12.9	7.7
Th	2.9	4.9	3.5	4.9	3.2	13.2	9.4	12.9	3.1	10.1	10.3	3.9
U	1.29	2.90	1.56	1.25	1.86	2.43	1.48	2.75	1.70	2.45	2.43	2.58
Zr#	69	106	188	234	114	192	171	387	96	193	316	95
Nb	2.73	4.22	5.38	5.40	4.31	19.94	12.44	14.89	4.55	13.18	14.55	4.33
Ta	0.18	0.33	0.40	0.40	0.31	1.47	0.97	1.14	0.30	0.98	1.11	0.31
Hf	1.79	2.25	4.56	6.01	2.89	5.61	4.77	9.61	2.72	5.19	8.12	2.53
Y	18.62	26.01	15.84	14.48	22.41	37.11	25.36	38.57	25.15	30.71	31.09	22.77
La	12.60	18.54	12.69	16.32	11.82	41.57	27.00	52.39	14.75	31.61	27.90	15.93
Ce	23.98	30.17	22.61	31.45	19.81	77.00	51.73	97.20	28.10	57.92	52.26	29.46
Pr	3.09	4.12	2.85	3.43	2.85	8.75	5.77	10.81	3.56	6.87	6.29	3.87
Nd	13.70	17.50	11.41	13.48	12.22	33.73	22.49	42.00	15.83	27.02	25.14	17.39
Sm	3.77	4.14	2.64	3.01	3.26	7.49	5.07	8.81	4.13	6.09	5.56	4.34
Eu	1.00	1.20	0.61	0.65	0.65	1.59	1.04	1.94	1.18	1.28	1.18	1.46
Gd	3.86	3.98	2.55	2.72	3.39	6.81	4.57	7.07	4.34	5.53	4.94	4.26
Tb	0.59	0.64	0.40	0.42	0.57	1.12	0.75	1.14	0.69	0.91	0.84	0.67
Dy	3.54	3.98	2.50	2.49	3.58	6.75	4.45	6.63	4.32	5.52	5.22	3.99
Ho	0.72	0.89	0.52	0.50	0.77	1.39	0.91	1.33	0.91	1.15	1.10	0.83
Er	1.88	2.45	1.45	1.37	2.21	3.71	2.46	3.53	2.48	3.06	3.05	2.26
Tm	0.27	0.36	0.22	0.20	0.32	0.55	0.37	0.53	0.37	0.45	0.46	0.33
Yb	1.69	2.23	1.50	1.32	2.20	3.33	2.32	3.30	2.29	2.87	2.91	2.15
Lu	0.26	0.34	0.24	0.22	0.36	0.52	0.36	0.52	0.37	0.45	0.46	0.34
Sc	32.86	23.80	4.64	4.20	11.43	21.68	13.70	11.01	22.94	16.73	12.96	18.46
V#	278	395	43	23	66	120	99	87	210	89	83	264
Cr#	44	146	20	16	30	81	75	49	40	67	52	63
Ni#	17	10	6	10	15	45	37	35	14	58	18	32
Cu#	133	45	15	10	24	40	26	52	70	55	11	109
Zn#	203	47	24	22	51	100	92	55	142	133	52	116
Ga#	17	21	5	4	10	24	17	14	18	18	15	16
Calculated Ratios												
$Eu/Eu^{*\#\#}$	0.80	0.91	0.72	0.70	0.60	0.68	0.66	0.75	0.85	0.68	0.69	1.04
$La_N/Yb_N^{\#\#\#}$	5.3	6.0	6.1	8.9	3.8	9.0	8.3	11.4	4.6	7.9	6.9	5.3

Notes: Major element analyses by XRF and normalized to 100% (volatile free). Trace element analyses performed by ICP-MS except thosedenoted by superscript "#" which are perfumed by XRF.

$Eu/Eu^* = Eu_N/(Sm_N * Gd_N)^{1/2}$ (Taylor and McLennan, 1985).

Subscript "N" denotes values normalised to chondrite values of Sun and McDonough (1989).

TABLE 1. CON'T

RC99 14	RC99 15	RC99 16	RC99 17	98JU 250	98JU 515	98JU 624	PE99 24	PE99 40	PE99 43	PE99 44	PG99 691
59.95	75.05	60.29	73.86	80.90	75.61	87.23	74.72	64.34	62.33	55.19	62.33
15.89	12.13	16.25	9.71	8.24	11.59	7.08	13.10	20.32	17.97	18.67	21.07
0.942	0.663	0.767	0.570	0.492	0.569	0.450	0.677	1.063	0.938	0.711	0.832
5.84	4.10	6.59	4.05	2.04	2.95	1.57	5.46	6.92	6.88	7.08	7.89
0.057	0.095	0.110	0.092	0.037	0.138	0.028	0.062	0.063	0.074	0.134	0.140
8.29	1.37	7.09	4.92	3.60	1.79	0.26	1.48	0.56	3.55	7.12	0.26
3.32	2.54	3.48	3.07	1.21	3.17	0.30	1.84	2.36	3.50	4.02	2.18
2.28	2.04	2.55	1.85	1.67	2.64	0.87	1.13	2.73	3.11	2.25	3.49
3.09	1.91	2.51	1.60	1.70	1.45	2.10	1.40	1.47	1.48	4.49	1.63
0.354	0.103	0.377	0.271	0.101	0.097	0.096	0.133	0.169	0.157	0.337	0.180
1047	2516	2128	1637	463	1335	244	259	424	627	799	966
53.16	57.12	45.73	46.30	57.8	105.7	32.5	70.2	129.5	145.5	75.8	158.7
1.75	1.67	2.70	2.20	1.86	10.03	1.44	2.58	3.96	9.33	2.51	6.71
787	307	827	363	200	119	129	118	196	230	430	247
4.2	9.4	5.5	9.8	9.9	13.6	7.3	16.4	21.4	19.0	5.8	19.6
5.0	5.5	2.7	3.2	6.8	8.2	6.4	9.9	15.3	14.8	3.4	13.6
1.94	1.85	1.28	2.12	1.70	1.66	1.51	2.36	3.02	2.81	1.62	2.63
156	130	94	88	245	146	363	274	246	242	69	141
10.10	8.11	5.10	6.86	9.79	11.79	9.25	18.04	20.87	21.27	3.45	19.45
0.64	0.59	0.33	0.48	0.74	0.87	0.68	1.25	1.53	1.60	0.22	1.42
3.95	3.65	2.55	2.15	6.12	4.01	8.47	7.36	7.10	7.74	1.94	4.74
26.95	29.52	22.65	24.51	22.84	23.06	19.46	26.17	31.84	40.50	18.84	32.69
26.45	18.69	16.25	15.14	24.96	19.06	22.90	26.92	21.87	47.43	13.70	30.56
47.23	33.60	30.19	22.01	49.86	39.56	45.50	56.48	51.30	91.98	27.38	73.67
5.91	4.29	3.81	3.34	5.32	4.20	4.82	6.04	5.01	10.48	3.40	6.86
23.93	17.47	16.27	14.08	20.74	16.65	18.37	23.66	19.47	41.87	15.21	27.29
5.51	4.44	4.21	3.67	4.46	3.69	3.80	5.29	4.65	9.43	3.94	6.51
1.61	1.40	1.39	0.89	1.01	0.87	0.82	1.19	1.08	1.94	1.23	1.40
5.04	4.60	4.08	3.89	4.19	3.63	3.47	4.47	4.45	7.99	3.69	5.86
0.79	0.79	0.67	0.62	0.65	0.61	0.57	0.76	0.82	1.32	0.58	1.00
4.65	5.12	4.03	3.78	3.98	3.92	3.46	4.56	5.32	7.83	3.48	6.32
0.96	1.11	0.84	0.78	0.82	0.82	0.70	0.94	1.16	1.55	0.71	1.29
2.53	3.11	2.29	2.19	2.19	2.38	1.95	2.80	3.41	4.14	1.90	3.53
0.38	0.48	0.33	0.32	0.34	0.35	0.29	0.46	0.53	0.61	0.28	0.53
2.36	3.16	2.13	2.00	2.12	2.35	1.85	3.18	3.43	3.78	1.74	3.35
0.38	0.54	0.34	0.32	0.35	0.38	0.30	0.52	0.55	0.60	0.28	0.55
19.82	22.94	19.96	13.85	6.8	15.4	5.0	15.8	20.7	24.5	26.9	26.1
179	146	207	111	42	72	33	76	127	99	169	124
77	70	48	142	26	65	25	45	87	82	38	83
27	36	20	86	9	37	9	30	43	42	18	60
40	130	113	56	12	94	6	30	38	17	78	63
89	92	80	120	31	78	16	71	88	106	94	104
17	16	18	10	10	15	9	16	27	21	16	26
0.93	0.95	1.02	0.72	0.71	0.72	0.69	0.75	0.73	0.68	0.99	0.69
8.0	4.2	5.5	5.4	8.4	5.8	8.9	6.1	4.6	9.0	5.7	6.5

TABLE 3-2. ROCK TYPE, Sm AND Nd CONCENTRATIONS, AND ISOTOPIC DATA

Sample	Rock type*	Petrography#	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$**	T_{DM}## (Ga)	eNd_{220}###
RC99-1	siltstone	QP	4.33	18.09	0.1446	0.512758 ± 6	0.89	+3.8
RC99-2	C-rich silty-sandstone	U	3.50	16.09	0.1314	0.512587 ± 11	1.07	+0.8
RC99-3	sandy-siltstone	QR	1.72	6.89	0.1514	0.512220 ± 9	2.30	-6.9
RC99-4	sandy-siltstone	QR	2.09	9.59	0.1316	0.512168 ± 6	1.84	-7.3
RC99-5	sandy-siltstone	QR	2.52	9.30	0.1636	0.512474 ± 11	2.09	-2.3
RC99-6	phyllite (silt)	QR	8.35	36.90	0.1368	0.512096 ± 7	2.11	-8.9
RC99-7	C-rich phyllite (mud-silt)	QR	2.48	10.80	0.1387	0.512114 ± 9	2.12	-8.6
RC99-8	phyllite (silt-sand)	QR	4.75	20.45	0.1403	0.512118 ± 11	2.16	-8.6
RC99-9	phyllite (mud-sand)	U	3.81	16.24	0.1420	0.512738 ± 7	0.90	+3.5
RC99-10	siltstone	QR	7.50	35.70	0.1269	0.512185 ± 7	1.71	-6.9
RC99-11	siltstone	QR	5.55	27.72	0.1210	0.512053 ± 8	1.82	-8.5
RC99-12	phyllite (mud-silt)	QP	4.49	18.84	0.1442	0.512765 ± 11	0.87	+4.0
RC99-14	limey-siltstone	U	4.60	22.03	0.1263	0.512776 ± 8	0.68	+4.7
RC99-15	siltstone	QR	4.07	17.87	0.1378	0.512356 ± 7	1.62	-3.9
RC99-16	sandy-siltstone	QP	3.55	16.02	0.1338	0.512832 ± 7	0.63	+5.6
RC99-17	sandy-siltstone	U	3.52	14.95	0.1424	0.512322 ± 7	1.79	-4.6
98JU-250	sandy-siltstone	QR	4.18	21.10	0.1198	0.512119 ± 7	1.69	-8.0
98 JU-515	siltstone	QR	3.59	17.32	0.1254	0.512124 ± 8	1.79	-8.0
98JU-624	pyritic sandstone	QR	3.96	20.85	0.1148	0.512104 ± 6	1.63	-8.1
PE99-24	phyllite (mud-silt)	QR	6.24	30.87	0.1221	0.512111 ± 12	1.75	-8.2
PE99-40	phyllite (mud-sand)	U	4.56	21.15	0.1303	0.512115 ± 9	1.91	-8.3
PE99-43	siltstone	QR	10.24	43.56	0.1422	0.512092 ± 7	2.27	-9.1
PE99-44	silty-sandstone	QP	3.23	14.04	0.1392	0.512662 ± 8	1.02	+2.1
PG99-691	muddy-siltstone	U	5.96	29.42	0.1225	0.512135 ± 8	1.71	-7.7
8006G###	not available	not available	6.00	33.18	0.1139	0.511902 ± 17	1.92	-12.0
8035A###	not available	not available	2.94	14.34	0.1229	0.511897 ± 30	2.12	-12.4
88GJ-88*****	argillite	not available	ND	18.79	0.0978	0.512256 ± 8	1.19	-4.7

Notes: ND - no data

*All rocks are chlorite to biotite grade metamorphic rocks except of PE 99-40 and PE 99-24, which are garnet-grade. Grain size of detrital particles is given for comparitive purposes.

#QR - quartz-rich group (>40% quartz, 0-<10% plagioclase), QP- quartz-poor group (<30% quartz, up to 40% plagioclase), U-undetermined because too fine-grained

** ± 2 SE

##Based on the model of Goldstein (1984).

###Where $eNd_{(T)} = [(^{143}Nd/^{144}Nd)_{Sample(T)}/^{143}Nd/^{144}Nd_{CHUR(T)})-1]*10^4$ (DePaolo and Wasserburg, 1976), values used were $^{143}Nd/^{144}Nd_{CHUR,today} = 0.512638$ (Goldstein, 1984) and $^{147}Sm/^{144}Nd_{CHUR,today} = 0.1966$ (Jacobson and Wasserburg, 1980).

###Data from Ghosh and Lambert (1989).

*****Data from Patchett and Gehrels (1998).

Table 3-3. Sample locations

sample	latitude (N)	longitude (W)
RC99-1	50.253	118.742
RC99-2	50.240	118.606
RC99-3	50.235	118.606
RC99-4	50.218	118.549
RC99-5	50.219	118.548
RC99-6	50.167	117.785
RC99-7	50.214	117.720
RC99-8	50.142	117.608
RC99-9	49.407	117.195
RC99-10	49.448	117.176
RC99-11	49.448	117.176
RC99-12	49.283	117.212
RC99-14	50.138	120.284
RC99-15	50.257	120.231
RC99-16	50.528	120.253
RC99-17	50.778	120.323
98JU-250	50.419	119.095
98 JU-515	50.366	119.098
98JU-624	50.400	118.958
98JU-162	50.438	119.138
PE99-24	50.497	119.443
PE99-40	50.506	119.467
PE99-43	50.275	119.157
PE99-44	50.387	119.309
PG99-691	50.451	119.009

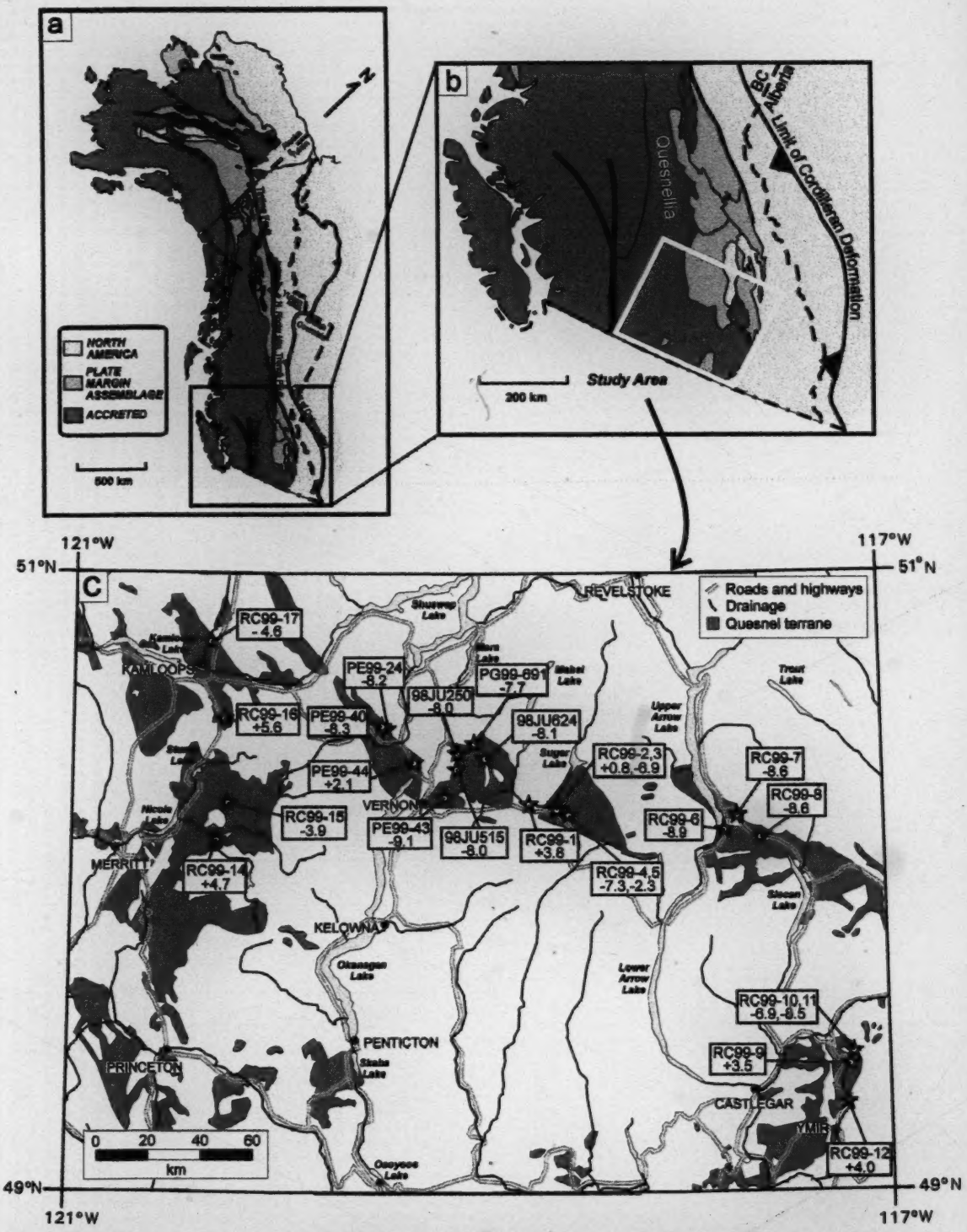


Figure 3-1. Maps showing a) the North American Cordillera in Canada and Alaska, differentiating rocks presently interpreted to be North American, plate margin assemblage, and accreted assemblages; b) outline of the Quesnel terrane and study area; and c) rocks of the Quesnel terrane (in gray), together with sample locations and Nd_{220} values determined in this study (modified from Wheeler and McFeely, 1991). See text for discussion.

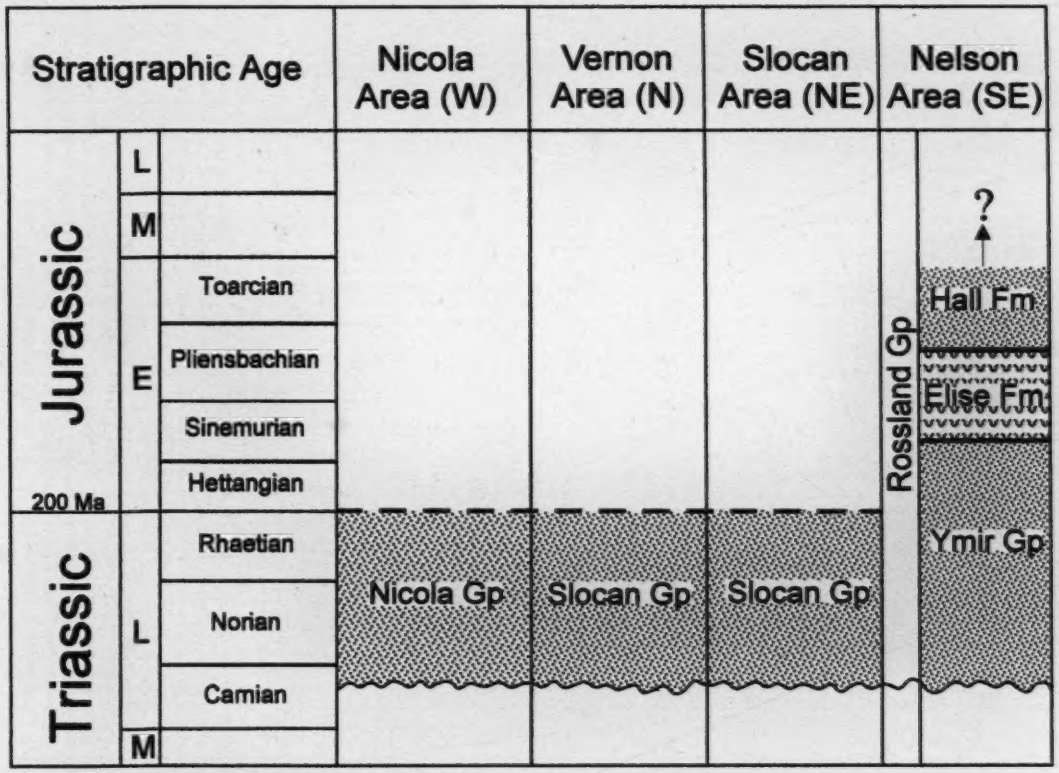


Figure 3-2. Stratigraphic correlation chart of Triassic metasedimentary rocks in southeastern British Columbia (after Little, 1960; Okulitch and Cameron, 1976; Klepacki and Wheeler, 1985; Höy and Andrew, 1988).

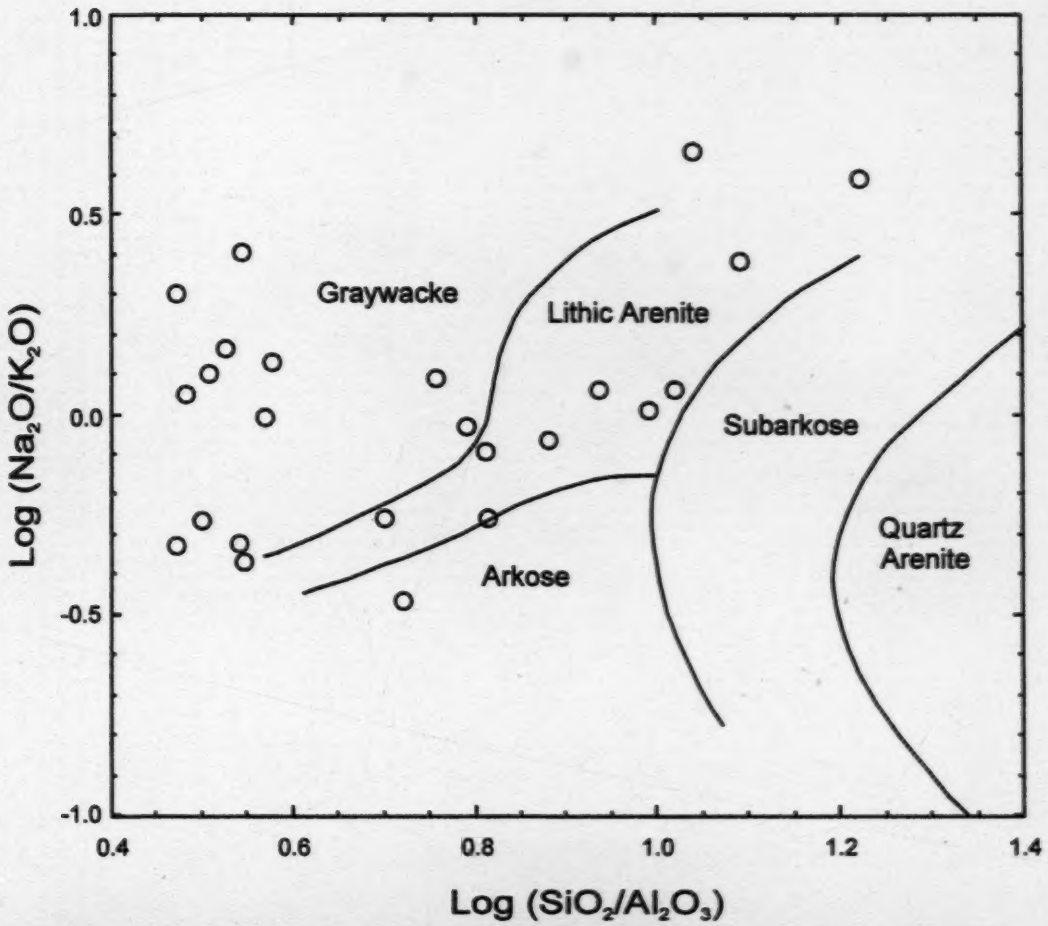


Figure 3-3. Chemical classification diagram of Pettijohn et al. (1987), showing analyzed samples falling in the fields of graywacke (n = 14), lithic arenite (n = 9) and arkose (n = 1).

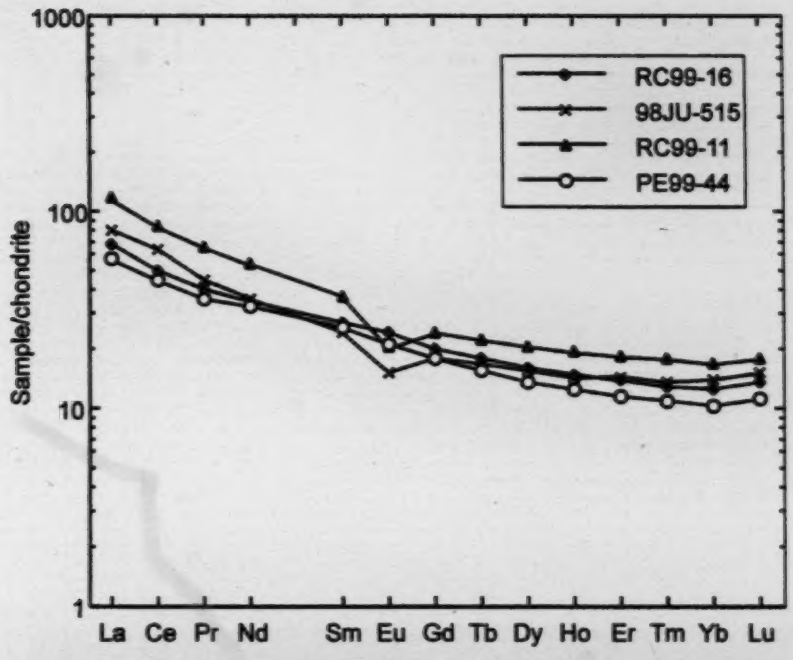


Figure 3-4. Chondrite normalized (Sun and McDonough, 1989) REE plot showing end member examples of primitive (RC99-16, RC99-11) and evolved (98JU515, PE99-44) Triassic metasedimentary rocks in southeastern British Columbia.

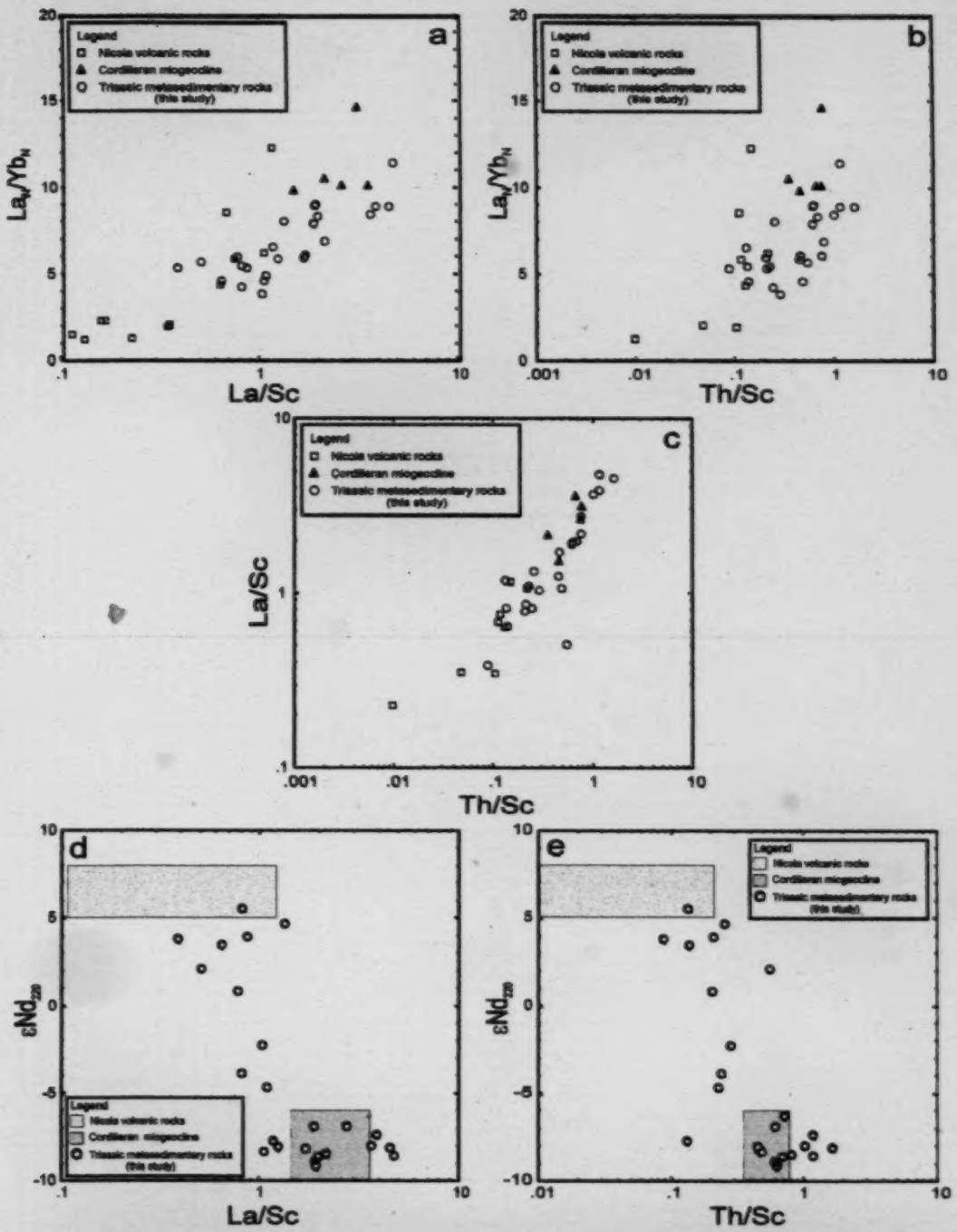


Figure 3-5. Plots a-c: Trace element variation diagrams for Triassic metasedimentary rocks; results overlap and are intermediate between values from the Nicola Group volcanic rocks (Mortimer, 1987) and sedimentary rocks of the North American miogeocline (data from Devonian strata, Garzione et al.,1997). Plots d,e: relationship between trace element ratios and Nd_{220} values of Triassic metasedimentary rocks that both overlap and are intermediate between values for the Nicola Group volcanic rocks (Nd isotopic data from Smith et al., 1995) and sedimentary rocks of the North American miogeocline (Nd isotopic data from Mississippian-Triassic strata from Jackson, 1992; Boghossian et al.1996; and Garzione et al., 1997).

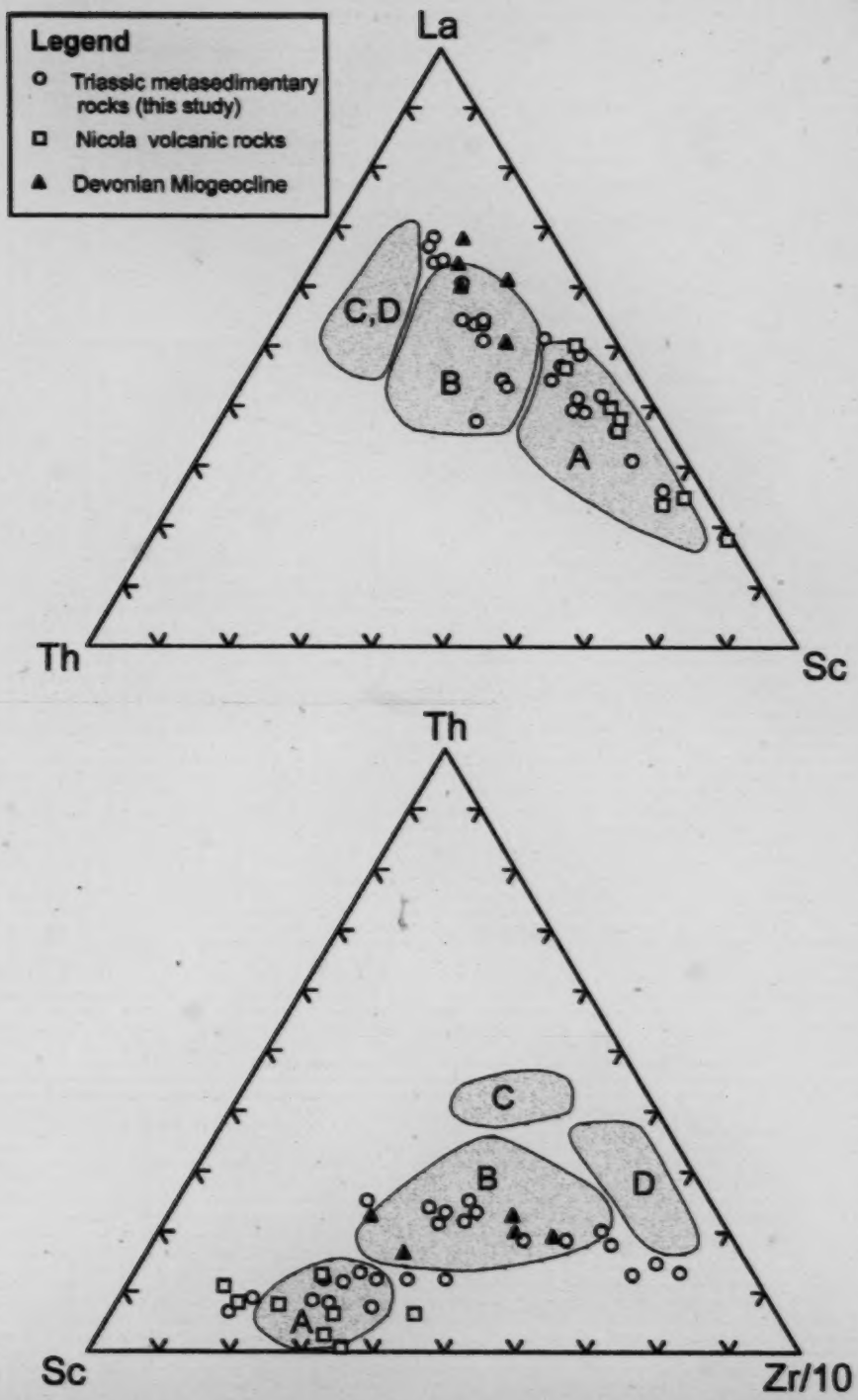


Figure 3-6. Tectonic discrimination diagrams for graywakes from Bhatia and Crook (1986); fields displayed are A: oceanic island arc, B: continental island arc, C: active continental margin, D: passive margin. Plotted for comparisonare data from Nicola Group volcanic rocks, (Mortimer, 1987) and Devonian strata of the North American miogeocline (Garzione et al., 1997).

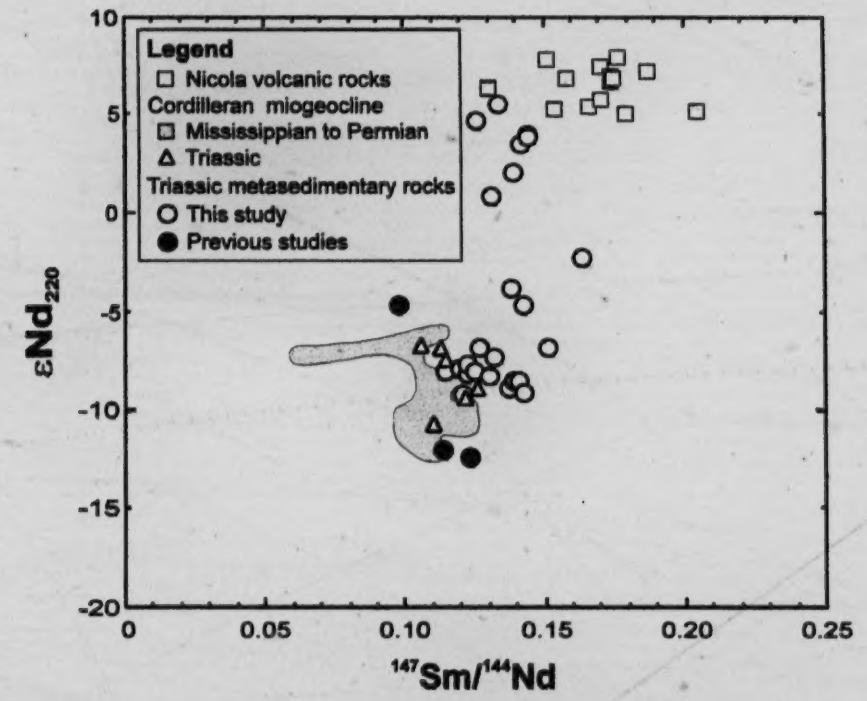


Figure 3-7. Sm-Nd isotopic data from Triassic metasedimentary rocks in southeast British Columbia. Shown for comparison are data from Mississippian to Triassic strata of the Canadian Cordilleran miogeocline (Jackson, 1992; Boghossian et al., 1996; Garzione et al., 1997) and volcanic rocks of the Upper Triassic Nicola Group (Smith et al., 1995). The Triassic metasedimentary rocks overlap the area between miogeocline and Nicola Group values and are compatible with a mixed origin between these sources.

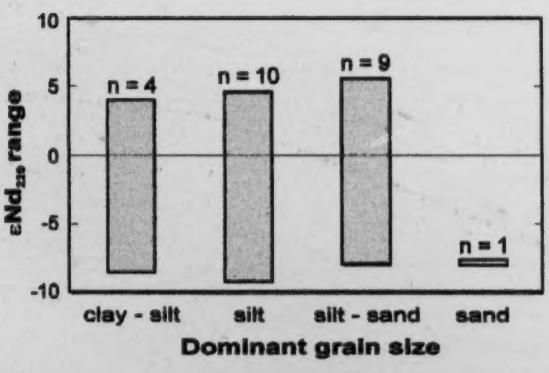


Figure 3-8. Plot of grain size against Nd isotopic composition, showing an absence of correlation in the analyzed samples. Grain size was measured by graduated ocular in thin section.

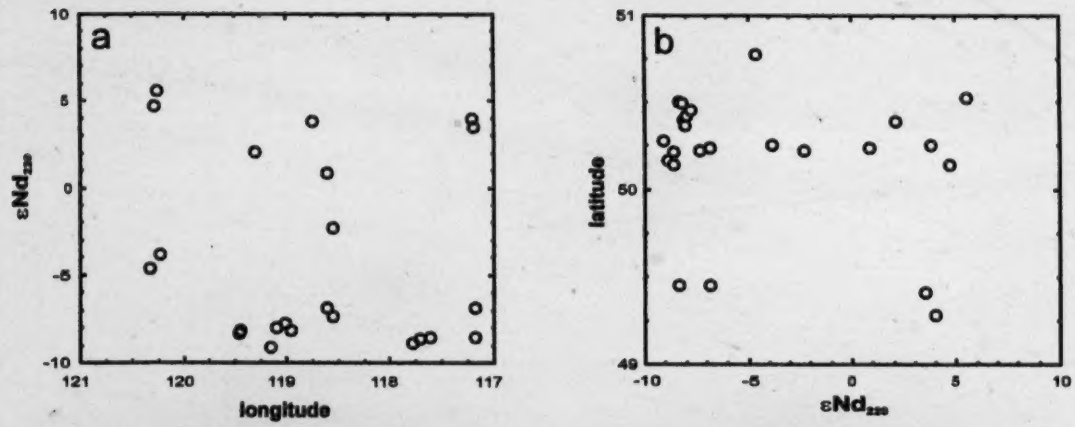


Figure 3-9. Distribution of Nd_{220} values of Triassic metasedimentary rocks in southeastern British Columbia in (a) east-west and (b) north-south directions.

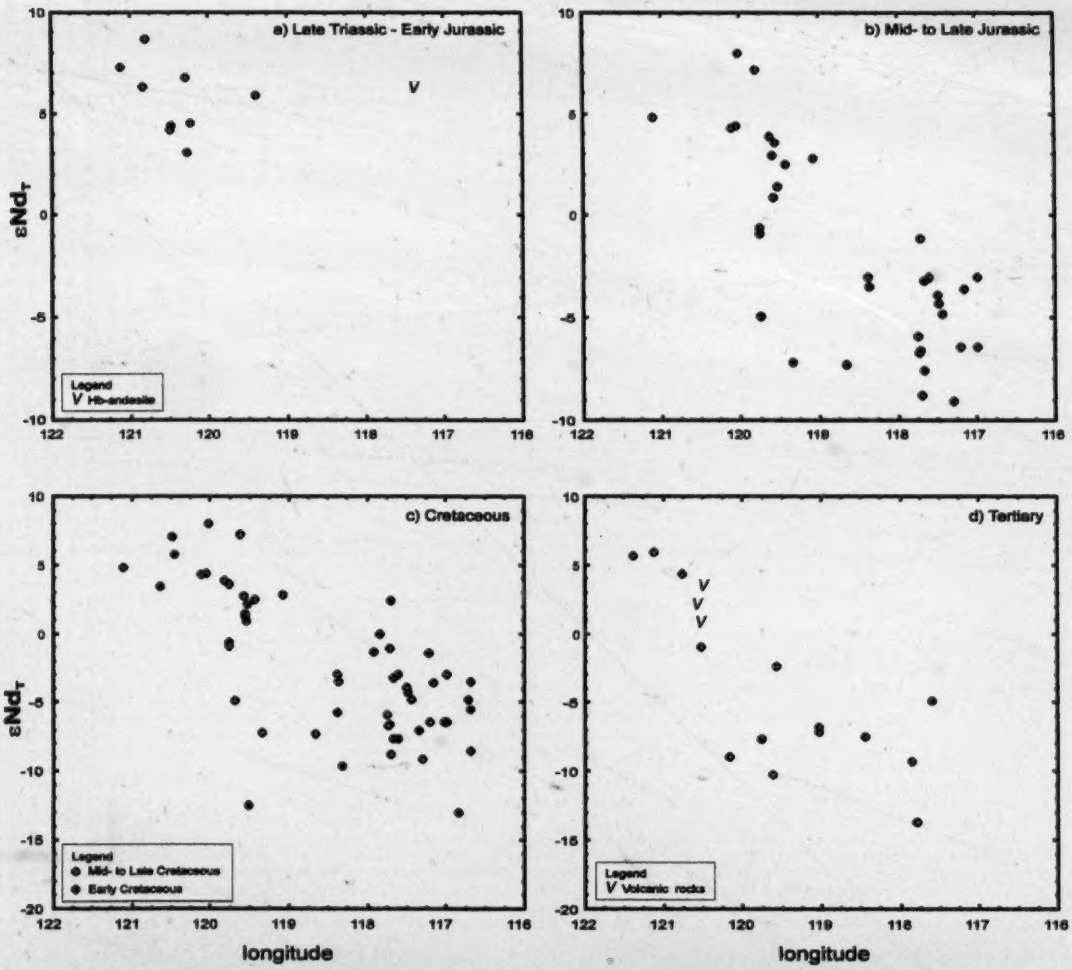


Figure 3-10. East-west distribution of εNd_T values of igneous rocks intruding the Quesnel terrane in southeastern British Columbia from Ghosh (1995). All samples are from intrusive igneous rocks except where noted. Periods are (a) Late Triassic to Early Jurassic, (b) Middle to Late Jurassic, (c) Cretaceous and (d) Tertiary. With the exception of a single volcanic rock (Fig 10a), Nd_T values become consistently more evolved from west to east over all time periods. See text for discussion.

References

Bhatia, M.R., and Crook, K.A.W., 1986, Trace element characteristics of graywackes and tectonic setting discrimination of sedimentary basins: Contributions to Mineralogy and Petrology, v. 92, p. 181-193.

Boghossian, N.D., Patchett, P.J., Ross, G.M., and Gehrels, G.E., 1996, Nd Isotopes and the Source of Sediments in the Miogeocline of the Canadian Cordillera: The Journal of Geology, v. 104, p. 259-277.

Cook, F.A., J.L. Varsek, R.M. Clowes, E.R. Kanasewich, C.S. Spencer, R.R. Parrish, R.L. Brown, S.D. Carr, B.J. Johnson and R.A. Price, 1992, LITHOPROBE crustal reflection structure of the southern Canadian Cordillera 1, foreland thrust and fold belt to Fraser River fault: Tectonics, v. 11, p. 12-35.

Creaser, R.A., Erdmer, P., Stevens, R.A. and Grant, S.L., 1997, Tectonic affinity of Nisutlin and Anvil assemblage strata from the Teslin tectonic zone, northern Canadian Cordillera: Constraints from neodymium isotope and geochemical evidence: Tectonics, v. 16, no. 1, p. 107-121.

DePaolo, D.J., and Wasserburg, G.J., 1976, Nd isotopic variations and petrogenetic models: Geophysical Research Letters: v. 3, p.249-252.

Dostal, J., Church, B.N., Höy, T., 2001, Geological and geochemical evidence for variable magmatism and tectonics in the southern Canadian Cordillera: Paleozoic to Jurassic suites, Greenwood, southern British Columbia: Canadian Journal of Earth Sciences, v. 38, p. 75 - 90.

Erdmer, P., Heaman, L., Creaser, R.A., Thompson, R.I., and Daughtry, K.L., 2001a, Eocambrian granite clasts in southern British Columbia shed light on Cordilleran hinterland crust: Canadian Journal of Earth Sciences, v. 38, p. 1007 - 1016.

Erdmer, P., Moore, J., Heaman, L., Thompson, B., Daughtry, K., and Creaser, R., 2001b, The Bob Lake assemblage, amphibolite-grade rocks atop Proterozoic basement in the Nicola horst: the Ancient Margin gets wider beneath "Quesnellia", *in* Cook, F. and Erdmer, P. (compilers), Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (February 25-27), University of Calgary, Lithoprobe Report No. 79, p. 241 - 242.

Feng, R., Kerrich, R., and Maas, R., 1992, Geochemical, oxygen, and neodymium isotope compositions of metasediments from the Abitibi greenstone belt and Pontiac Subprovince, Canada: Evidence for ancient crust and Archean terrane juxtaposition: Geochimica et Cosmochimica Acta, v. 57, p.641-658.

Frost, C.D., and Coombs, D.S., 1989, Nd isotope character of New Zealand sediments: Implications for terrane concepts and crustal evolution: American Journal of Science, v. 289, p. 744 - 770.

Gabrielse, H., Monger, J.W.H., Wheeler, J.O. and Yorath, C.J., 1991, Part A: Morphogeological belts, tectonic assemblages, and terranes, *in* Gabrielse H. and Yorath, C.J., eds., Geology of the Cordilleran Orogen in Canada: Ottawa, Geological Survey of Canada, No. 4., p. 15-28. (also Geological Society of America, The Geology of North America, **G-2)**

Garzione, C.N., Patchett, P.J., Ross, G.M. and Nelson, J., 1997, Provenance of Paleozoic sedimentary rocks in the Canadian Cordilleran miogeocline: a Nd isotopic study: Canadian Journal of Earth Sciences, v. 34, p. 1603-1618.

Ghosh, D.K., 1995, Nd-Sr isotopic constraints on the interactions of the Intermontane Superterrane with the western edge of North America in the southern Canadian Cordillera: Canadian Journal of Earth Sciences, v. 32, p. 1740-1758.

Ghosh, D.K. and Lambert, R.S., 1989, Nd-Sr isotopic study of Proterozoic to Triassic sediments from southeastern British Columbia: Earth and Planetary Science Letters, v. 94, no. 1-2, p. 29-44.

Goldstein, S.L., O'Nions, R.K., and Hamilton, P.J., 1984, A Sm-Nd isotopic study of atmospheric dusts and particulates from major river systems: Earth and Planetary Science Letters, v. 70, 221-236.

Hollister, V.F., 1976, Porphyry copper province of northern Cordilleran orogen - summary, *in* Circum-Pacific energy and mineral resources, Halbouty, M.T., Maher, J.C., and Lian, H.M.: Tulsa, American Association of Petroleum Geologists, p. 509-515.

Höy, T., and Andrew, K., 1988, Preliminary geology and geochemistry of the Elise Formation, Rossland Group, between Nelson and Ymir, southeastern British Columbia (82F/06): B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1987, Paper 1988-1, p. 19-30.

Höy, T., and Andrew, K., 1991, Geology of the Rossland area, southeastern British Columbia (82F/4E): B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1990, Paper 1991-1, p. 21-31.

Jackson, J.L., 1992, Tectonic analysis of the Nisling, northern Stikine and northern Cache Creek terranes, Yukon and British Columbia [PhD thesis]: Department of Geosciences, The University of Arizona, 200 p.

Jacobsen, D.H., and Wasserburg, G.J., 1980, Sm-Nd isotopic evolution of chondrites: Earth and Planetary Science Letters, v. 50, p. 139-155.

Johnson, D.M., Hooper, P.R., and Conrey, R.M., 1999, XRF Analysis of Rocks and Minerals for Major and Trace Elements on a Single Low Dilution Li-tetraborate Fused Bead: Advances in X-ray Analysis, v. 41, p. 843-867.

Jones, A.G., 1959, Vernon Map-area British Columbia: Geological Survey of Canada Memoir 296, 186p.

Klepacki, D.W., 1983, Stratigraphic and Structural Relations of the Milford, Kaslo, and Slocan Groups, Roseberry Quadrangle, Lardeau Map Area, British Columbia: Current Research, Part A, Geological Survey of Canada, p. 229-233.

Klepacki, D.W., and Wheeler, J.O., 1985, Stratigraphic and structural relations of the Milford, Kaslo, and Slocan groups, Goat Range, Lardeau and Nelson map areas, British Columbia: Current Research, Part A, Geological Survey of Canada, p. 277-286.

Knaack, C., Cornelius, S., and Hooper, P., 1994, Trace Element Analyses of Rocks and Minerals by ICP-MS, Geoanalytical Library, Washington State University; Geology Department, Open File Report, 4p.

Little, H.W., 1960, Nelson map-area, west half, British Columbia: Geological Survey of Canada Memoir 308, 205p.

McLennan, S.M., and Hemming, S., 1992, Samarium/neodymium elemental and isotopic systematics in sedimentary rocks: Geochimica et Cosmochimica Acta, v. 56, p. 887 - 898.

McLennan, S.M., Hemming, S., McDaniel, D.K., and Hanson, G.N., 1993, Geochemical approaches to sedimentation, provenance, and tectonics: Geological Society of America Special Paper 284, p. 21 - 40.

McLennan, S.M., Hemming, S.R., Taylor, S.R., and Eriksson, K.A., 1995, Early Proterozoic crustal evolution: Geochemical and Nd-Pb isotopic evidence from metasedimentary rocks, southwestern North America: Geochimica et Cosmochimica Acta, v. 59, no. 6, p. 1153 - 1177.

McLennan, S.M., and Taylor, S.R., 1991, Sedimentary rocks and crustal evolution: Tectonic setting and secular trends: The Journal of Geology, v. 99, no. 1, p. 1 - 21.

Monger, J.W.H., 1977, Upper Paleozoic rocks of the western Canadian Cordillera and their bearing on Cordilleran Evolution: Canadian Journal of Earth Sciences, v. 14, p. 1832-1859.

Monger, J.W.H., 1985, Structural evolution of the southwestern Intermontane belt, Ashcroft and Hope map area, British Columbia: Current Research Part A, Geological Survey of Canada Paper 85 - 1A, p. 349-358.

Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J., 1982, Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera: Geology, v. 10, p. 70-75.

Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T., Struik, L.C., Campbell, R.B., Dodds, C.J., Gehrels, G.E., and O'Brian, J., 1991, Part B: Cordilleran terranes, *in* Gabrielse, H., Yorath, C.J., ed., Geology of the Cordilleran Orogen in Canada: Ottawa, Geological Survey of Canada, No. 4, p. 281-327. (also Geological Society of America, The Geology of North America, **G-2)**

Moore, J.M., Gabites, J.E., and Friedman, R.M., 2000, Nicola Horst: Toward a Geochronology and Cooling History, *in* Cook, F. and Erdmer, P. (compilers), Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (February 25-27), University of Calgary, Lithoprobe Report No. 72, p. 177 - 185.

Mortimer, N., 1986, Late Triassic, arc-related, potassic igneous rocks in the North American Cordillera: Geology, v. 14, p. 1035-1038.

Mortimer, N., 1987, The Nicola Group: Late Triassic and Early Jurassic subduction related volcanism in British Columbia: Canadian Journal of Earth Sciences, v. 4, p. 2521-2536.

Mortimer, N., van der Heyden, P., Armstrong, R.L., and Harakal J., 1989, U-Pb and K-Ar dates related to the timing of magmatism and deformation in the Cache Creek terrane and Quesnellia, southern British Columbia: Canadian Journal of Earth Sciences, v. 27, p. 117-123.

Nelson, B.K., and DePaolo, D.J., 1988, Comparison of isotopic and petrographic provenance indicators in sediments from Tertiary continental basins of New Mexico: Journal of Sedimentary Petrology, v. 58, no. 2, p. 348 - 357.

Okulitch, A.V., and Cameron, B.E.B., 1976, Stratigraphic revision of the Nicola, Cache Creek, and Mount Ida Group based on conodont collections from the western margin of the Shuswap Metamorphic Complex, south-central British Columbia: Canadian Journal of Earth Sciences, v. 13, p. 44-53.

Orchard, M.J, 1985, Carboniferous, Permian and Triassic Conodonts from the Central Kootenay Arc, British Columbia: Constraints on the Age of the Milford, Kaslo, and Slocan Groups: Current Research, Part A, Geological Survey of Canada, p. 287-300

Patchett, P.J., and Gehrels, G.E., 1998, Continental Influence on Canadian Cordilleran Terranes from Nd Isotopic Study, and Significance for Crustal Growth Processes: The Journal of Geology, v. 106, p. 269-280.

Pettijohn, F.J., Potter, P.E., Siever, R., 1987, Sand and Sandstone: New York, Springer-Verlag, 553p.

Preto, V.A., 1977, The Nicola Group: Mesozoic volcanism related to rifting in southern British Columbia, *in* Baragar, W.R.A., Coleman, L.C., and Hall, J.M., eds., Volcanic Regimes in Canada: Toronto, The Geological Association of Canada, Special Paper No. 16, p. 39-57.

Preto, V.A., Osatenko, M.J., Mc Millan, W.J., and Armstrong, R.L., 1979, Isotopic dates and strontium isotopic ratios for plutonic and volcanic rocks in the Quesnel Trough and Nicola Belt, south-central British Columbia: Canadian Journal of Earth Sciences, v. 16: 1658-1672.

Read, P.B., and Okulitch, A.V., 1977, The Triassic unconformity of south-central British Columbia: Canadian Journal of Earth Sciences, v. 14, p. 606-638.

Read, P.B., 1996, Kamloops to Vernon: Tertiary Stratigraphy and Structure, Industrial Mineral and Precious Metal Potentials, Kamloops, Nicola, and Vernon Mining Divisions: British Columbia Geological Survey, Assessment Report, 2 vol.

Roback, R.C., and Walker, N.W., 1995, Provenance, detrital zircon U-Pb geochronometry, and tectonic significance of Permian to Lower Triassic sandstone in southeastern Quesnellia, British Columbia and Washington: GSA Bulletin, v. 107, p. 665-675.

Schau, M.P., 1968, Geology of the Upper Triassic Nicola Group in South Central British Columbia [PhD thesis]: Vancouver, University of British Columbia.

Schau, M.P., 1970, Stratigraphy and structure of the type area of the Upper Triassic Nicola Group in south-central British Columbia, *in* Wheeler, J.O. ed, Structure of the Southern Canadian Cordillera: Toronto, Geological Association of Canada, Special Paper No. 6, p. 123-135.

Smith, A.D., Brandon, A.D., and Lambert, R.S., 1995, Nd-Sr isotope systematics of Nicola Group volcanic rocks, Quesnel terrane: Canadian Journal of Earth Sciences, v. 32, p. 437-446.

Souther, J.G., 1977, Volcanism and tectonic environments in the Canadian Cordillera - A second look, *in* Baragar, W.R.A., Coleman, L.C., and Hall, J.M., eds., Volcanic Regimes in Canada: Toronto, The Geological Association of Canada, Special Paper No. 16, p. 2-24.

Souther, J.G., 1991, Volcanic regimes, *in* Gabrielse, H., Yorath, C. J., ed., Geology of the Cordilleran Orogen in Canada: Ottawa, Geological Survey of Canada, No. 4, p. 459-490. (also Geological Society of America, The Geology of North America, **G-2)**

Struik, L.C., 1987, The ancient western North American margin: An alpine rift model for the east-central Canadian Cordillera: Geological Survey of Canada Paper 87-15, 19p.

Sun, S.-s. and McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes, *in* Saunders, A.D., and Norry, M.J., eds., Magmatism in Ocean Basins: London, Geological Society of London, Special Publication No. 42, p. 313-345.

Tanaka, T., Togashi, S., Kamioka, H., Amakawa, H., Kagami, H., Hamamoto, T., Yuhara, M., Orihashi, Y., Yoneda, S., Shimizu, H., Kunimaru, T., Takahashi, K., Yanagi, T., Nakano, T., Fujimaki, K., Shinjo, R., Asahara, Y., Tanimizu, M., and Dragusanu, C., 2000, JNdi-1: a neodymium isotopic reference in consistency with La Jolla neodymium: Chemical Geology, v. 168, p. 279-281.

Taylor, S.R., and McLennan, S.M., 1985, The Continental Crust: its Composition and Evolution: Oxford, Blackwell Scientific Publications, 312p.

Thompson, R.I., and Daughtry, K.L., 1996, New stratigraphic and tectonic interpretations, North Okanagan Valley, British Columbia: Current Research 1996-A, Geological Survey of Canada, p. 132-141.

Thompson, R.I., and Daughtry, K.L., 1997, Anatomy of the Neoproterozoic-Paleozoic continental margin, Vernon map-area, British Columbia: Current Research 1997-A, Geological Survey of Canada, p. 145-150.

Thompson, R.I., and Daughtry, K.L., 1998., Stratigraphic linkages across Vernon map area (82L), British Columbia: Current Research 1998-A, Geological Survey of Canada, p. 181-187.

Travers, W.B., 1977, Overturned Nicola and Ashcroft strata and their relation to the Cache Creek Group, Southwestern Intermontane Belt, British Columbia: Canadian Journal of Earth Sciences, v. 15, p. 99-116.

Unterschutz, J., Erdmer, P., Thompson, R.I., and Daughtry, K.L., 1999a, Transition from Neoproterozoic to Triassic stratigraphy, Silver Star Mountain, Vernon map area, British Columbia: Current Research 1999-A, Geological Survey of Canada, p. 199-204.

Unterschutz, J., Creaser, R.A., and Erdmer, P., 1999b, Nd isotopic and geochemical study of Triassic Quesnellian sedimentary rocks, Vernon area, SE British Columbia: Geological Society of America Abstracts with Programs, Annual Meeting, Denver, Colorado, p. A-374.

Varsek, J.L., and Cook, F.A., 1994, Three-dimensional crustal structure of the eastern Cordillera, southwestern Canada and northwestern United States. Geological Society of America Bulletin, v. 106, p. 503-823.

Wheeler, J.O., and McFeely, P., 1991, Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America: Geological Survey of Canada Map 1712A, 1:2 000 000 scale.

Chapter 4

Concluding Remarks

This dissertation presents two studies that examine the relationship between strata of the Quesnel "terrane" and ancestral North America in southeastern British Columbia, Canada, to further the understanding of the geological history of the west coast of North America, heretofore poorly understood. New geologic and geochemical data are presented and discussed to place constraints upon the paleogeographic setting in which the Quesnel "terrane" formed, during the Late Triassic - Early Jurassic. To address this objective, field mapping, petrographic studies, structural analysis, U-Pb geochronology, and Nd tracer isotope studies were combined.

Chapter 2 presents the geology of the Silver Star area, a region in which pericratonic North American rocks are in contact with rocks of the Quesnel "terrane". Field studies established that this contact is not exposed in the map area. Mapping suggests that a structural or stratigraphic discontinuity at this boundary is possible, and in that respect was inconclusive toward the main objective of this dissertation. However, indirect evidence, in the form of detrital zircons within Quesnel "terrane" strata, suggests that rocks of the Quesnel "terrane" in this area were derived from Early Jurassic volcanic sources (~183 – 192 Ma) to the east that intrude rocks of the North American margin, and thereby provides a depositional link between metasedimentary Quesnel strata in the Silver Star area and North American rocks.

Chapter 3 presents a regional provenance study of Upper Triassic metasedimentary rocks of the Quesnel terrane, using Nd isotope and trace element compositions. This study demonstrates a mixed provenance for these rocks (εNd_T between –10 to +5.5, La_N/Yb_N between 3.85 and 11.40, La/Sc between 0.38 and 4.76), including a consistent, widespread, and abundant detrital contribution from evolved continental crust, identical in composition to contemporaneous deposits of the Cordilleran miogeocline in British Columbia and the Yukon, Canada. These data also record a detrital contribution to this basin from rocks with a composition identical to the volcanic arc rocks of the Quesnel "terrane" to the west, and suggest that both sources were proximal to the sedimentary

basin. This study further establishes evidence for a depositional link, and a case for proximity, between the Quesnel "terrane" and North America.

This dissertation indicates that the Quesnel "terrane" in southeastern British Columbia developed in a paleogeographic setting that was proximal to the North American margin at its present, paleo-equivalent, latitude. This is in conflict with previous interpretations based on paleontologic and paleomagnetic data that described a more southerly origin for the Quesnel "terrane" (e.g. Carter et al. 1991; Taylor et al. 1984; Symons 1983; Irving et al. 1985; Rees et al. 1985; Symons 1985). However, while these data can be used to suggest a more southerly origin, the paleontologic data do not require it, and thus they do not necessarily preclude a parautochthonous origin for these rocks. A parautochthonous interpretation is supported by geologic relationships that describe unconformable contacts between Quesnel strata and rocks of North American origin (Jones 1959; Read and Okulitch 1977; Klepacki 1983; Klepacki and Wheeler 1985; Höy and Andrew 1991; Roback and Walker 1995; Thompson and Daughtry 1996, 1997, 1998), and igneous rocks intruding this "terrane" with Proterozoic inheritance, prior to the purported obduction of the Quesnel "terrane" onto the North American margin (Dostal et al. 2001). These data combine to suggest that the Quesnel "terrane" developed as a distal continental margin arc, overlapping North American strata in the east, and oceanic rocks in the west. These conclusions indicate that the categorization of Quesnel strata as a "terrane" is no longer appropriate, and pushes the boundary between North American and allochthonous rocks further west.

References

Carter, E.S., Orchard, M.J., Ross, C.A., Ross, J.R.P., Smith, P.L., and Tipper, H.W. 1991. Part B: Paleontological signatures of the terranes. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse and C.J. Yorath. Geological Survey of Canada, no. 4, pp. 28-38. (also Geological Society of America, The Geology of North America, **G-2)**

Dostal, J., Church, B.N., Höy, T., 2001. Geological and geochemical evidence for variable magmatism and tectonics in the southern Canadian Cordillera: Paleozoic to Jurassic suites, Greenwood, southern British Columbia. Canadian Journal of Earth Sciences, **38**:75 - 90.

Höy, T., and Andrew, K. 1991. Geology of the Rossland area, southeastern British Columbia (82F/4E). Geological Fieldwork 1990, Paper 1991-1, B.C. Ministry of Energy, Mines and Petroleum Resources, pp. 21-31.

Irving, E., Woodsworth, G.J., Wynne, P.J., and Morrison, A. 1985. Paleomagnetic evidence for displacement from the south of the Coast Plutonic Complex, British Columbia. Canadian Journal of Earth Sciences, **22**:584-598.

Jones, A.G. 1959. Vernon Map-area British Columbia. Geological Survey of Canada, Memoir 296, 186p.

Klepacki, D.W. 1983. Stratigraphic and Structural Relations of the Milford, Kaslo, and Slocan Groups, Roseberry Quadrangle, Lardeau Map Area, British Columbia. *In* Current Research, Part A. Geological Survey of Canada, pp. 229-233.

Klepacki, D.W., and Wheeler, J.O. 1985. Stratigraphic and structural relations of the Milford, Kaslo, and Slocan groups, Goat Range, Lardeau and Nelson map areas, British Columbia. *In* Current Research, Part A. Geological Survey of Canada, pp. 277-286.

Read, P.B., and Okulitch, A.V. 1977. The Triassic unconformity of south-central British Columbia. Canadian Journal of Earth Sciences. **14:** 606-638.

Rees, C.J., Irving, E., and Brown, R. L. 1985. Secondary magnetization of the Triassic-Jurassic volcaniclastic rocks of the Quesnel terrane, Quesnel Lake, B.C. Geophysical Research Letters, **12**(8):498-501.

Roback, R.C. and Walker, N.W. 1995. Provenance, detrital zircon U-Pb geochronometry, and tectonic significance of Permian to Lower Triassic sandstone in southeastern Quesnellia, British Columbia and Washington. Geological Society of America Bulletin, **107**(6):665-675.

Symons, D.T.A. 1983. New paleomagnetic data for the Triassic Guichon batholith of south-central British Columbia and their bearing on Terrane I tectonics. Canadian Journal of Earth Science, **20**:1340-1343.

Symons, D.T.A. 1985. Paleomagnetism of the Triassic Nicola volcanics and geotectonics of the Quesnellia subterrane of Terrane I, British Columbia. Journal of Geodynamics, **2**:229-244.

Taylor, D.G., Callomon, J.H., Hall, R., Smith, P.L., Tipper, H.W., and Westerman, G.E.G. 1984. Jurassic ammonite biogeography of western North America: The tectonic implications. *In* Jurassic-Cretaceous Biochronology and Paleogeography of North America. *Edited by* G.E.G. Westerman. Geological Association of Canada, Special Paper 27, pp. 121-141.

Thompson, R.I., and Daughtry, K.L. 1996. New stratigraphic and tectonic interpretations, North Okanagan Valley, British Columbia. *In* Current Research 1996-A. Geological Survey of Canada, pp. 132-141.

Thompson, R.I., and Daughtry, K.L. 1997. Anatomy of the Neoproterozoic-Paleozoic continental margin, Vernon map-area, British Columbia. *In* Current Research 1997-A. Geological Survey of Canada, pp. 145-150.

Thompson, R.I., and Daughtry, K.L., 1998. Stratigraphic linkages across Vernon map area (82L), British Columbia. *In* Current Research 1998-A. Geological Survey of Canada, pp. 181-187.